Appendix B

GTS Duratek Logging Procedures

Appendix B

GTS Duratek Logging Procedures

The GTS Duratek procedures for n-gamma data acquisition and processing, neutron-neutron moisture data acquisition and processing, passive neutron data acquisition and processing, and azimuthal gamma data acquisition and processing are included in this appendix.

TITLE:

Geophysical Log Data Analysis

Approved by

J. J. Dorian, Program Manager
Environmental Monitoring & Investigations

1.0 PURPOSE

This section describes the analysis of geophysical logging data (also called data reduction) to identify gamma-ray emitting radionuclides present in the sub-surface and quantify their concentrations in order to monitor the operating condition of nearby nuclear and/or non-nuclear facilities.

2.0 SCOPE

This section applies to Environmental Monitoring and Investigations (EM&I) personnel involved with geophysical logging and provides the minimum requirements for analyzing spectral gamma-ray survey data that was obtained by borehole geophysical logging for environmental investigation and site characterization.

3.0 REQUIREMENTS

3.1 POLICY IMPLEMENTATION

The Waste Management Federal Services, Inc., Northwest Operations (WMNW) *Operational Environmental Monitoring* manual provides employees with clear, documented guidelines consisting of policies, work procedures, performance requirements, process or equipment operational limits, and rules of conduct.

3.2 EMPLOYEE COMPLIANCE

Compliance to these documents is required of EM&I employees. Errors or deficiencies in these documents should be promptly reported to EM&I. If implementation and compliance to an established policy requirement or procedure cannot be achieved, work shall be immediately and safely stopped. Responsible management should be consulted for direction to proceed.

3.3 CHANGE PROCESS AND CONTROL

Revisions will be reviewed and approved by the EM&I Program Manager annually or as needed.

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3.4 REPORTS

Results of geophysical logging are documented in reports identified in Section 6.0 (Records) of this procedure.

3.5 SAFETY AND SECURITY

Safe work practices shall be followed at all times.

3.6 LOG ANALYSIS

Well logging shall take place as directed by the contractual customer and in accordance with the Geophysical Logging procedure described in Procedure 17.0. The log analysis procedures will be performed under operating procedures in Attachment A to this section. A description of the software program algorithms, input parameters, input files, and output files are presented in Attachment B to this section.

The minimum detection limits for the High Purity Germanium (HPGe) radionuclide logging system (RLS) are determined using the methods described in Attachment C.

Gamma ray attenuation shielding corrections are determined as described in Attachment D.

The RLS HPGe system dead time corrections are determined as indicated in Attachment E.

Well log data analysis results are maintained in the designated manner and at places that satisfy protocols identified in Procedure 4.0 of this manual.

Completed well log analysis results are archived at 345 Hills Street in Richland, Washington.

3.6.1 Contract Documents

1. When contracted log analysis is required for data reduction of survey logs, the logging geophysicist prepares the log analysis requirements to be included in or attached to the contract document.

2. The contractor must provide documentation of (and the cognizant manager or team lead must approve) log analysis training, expertise, and experience.

3. The contractor shall either use the log analysis procedures of WMNW or submit log analysis procedures to the WMNW logging geophysicist for approval.

4. The work order/statement of work (SOW) should be delivered to the contractor two weeks prior to log analysis and shall contain at least the following requirements:

   a. Personnel qualifications and training.

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b. Minimum requirements for analysis of log data.

c. Request for a copy of the log analysis procedures for WMNW approval or written communication of intent to use WMNW log analysis procedures, prior to the start of work.

d. Detailed special log analysis requirements, when applicable.

e. Requirements for records maintenance and turnover to WMNW.

f. List of deliverables to contractor for analysis of the logging data and list of deliverables returned by the contractor to WMNW. The list shall at a minimum include the number and depth of wells, detector types, and type of data (hardcopy/digital).

4.0 RESPONSIBILITIES

4.1 QUALIFICATIONS

The log analyst and log analysis technician must demonstrate training and qualification to the satisfaction of the cognizant program manager. Qualification of personnel shall be documented and the documentation maintained by the WMNW training coordinator.

4.2 LOG ANALYST (SCIENTIST)

1. Oversee analysis of log data reduction tasks, and interface with Logging Geophysicist and project scientists/engineers.

2. Review draft remedial investigation plans or other plans involving subsurface investigations, and ensures that log data analysis requirements are included in work plans or contract documents.

3. Prepare logging requirements for inclusion in contract documents (at a minimum, include the requirements of Section 3.6.1 of this procedure).

4. Review this instruction for applicability to new log analysis methods as they become available, and implement changes/revisions as required.

5. Prepare new log analysis procedures for review and approval, as new methods become available.

4.3 LOG ANALYSIS TECHNICIAN

1. Stay apprised of changes in log analysis methods.

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2. Perform analysis of borehole survey data~~, review output of~~ analysis software, report unusual conditions to the Log Analyst, and prepare analysis results files.

3. Ensure that log analysis and records disposition is performed in accordance with this procedure.

5.0 FORMS

Borehole Survey - Data Analysis Form (Figure 1).

6.0 RECORDS

Record processing and disposition shall be performed in accordance with the following table.

Name Filing Unit Title or Description	Record Type	Retention Period	Disposal Authority	Cut-off and Retirement Instructions
Borehole Survey - Data Analysis Form	INFO	TBD	TBD	Log Analyst verifies a completed Borehole Survey - Data Analysis Form is filed with the completed borehole log analysis reports that are archived at 345 Hills Street in Richland, Washington.
Log Analysis Reports	QA	TBD	TBD	Log Analyst verifies the completed borehole log analysis reports are archived at 345 Hills Street in Richland, Washington.
Calibration Certificate	QA	TBD	TBD	The original Calibration Certificate will be provided to the FC for transmittal to permanent storage per approved RIDS.
Archive Disks	Record	TBD	TBD	Duplicate archive disks will be provided to the FC and stored in record files.

QA – Quality Assurance.
INFO – Information Record.
TBD – To Be Determined (dependent upon individual logging contract).

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Figure 1. Borehole Survey Data Sheet

BOREHOLE SURVEY DATA SHEET

Project: | Well Name: | Well ID:

Date: | Location:

Notes:

BOREHOLE LOGGING INFORMATION

Logger: ______ Logging Unit Configuration: ______

Depth Datum Reference: ______ Instrument Calibration Configuration: ______

Total Well Depth: ______ ft Source: ______ Water Level: ______ ft Source: ______

Source for Casing Parameters: ______

Casing
Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

File Name Prefix: ______ Field Disk/Part ______ Return Error: ______ in. (High/Low) at ______ ft Field Verifier ID: ______

Pre Log Verification: Gross ______ c/s Background ______ c/s Th 583 keV photo peak FWHM ______

Post Log Verification: Gross ______ c/s Background ______ c/s Th 583 keV photo peak FWHM ______

Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft
Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft
Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft
Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft

LOGGING OPERATIONS WERE PERFORMED AND EQUIPMENT CLEANED AS PER PROCEDURES, 17.0 GEOPHYSICAL LOGGING WASTE MANAGEMENT - NORTHWEST

Prepared by (print) ______

Signature:

Date: ______

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7.0 BIBLIOGRAPHY

API, 1974, *Recommended Practice for Standard Calibration and Format for Nuclear Logs*, RP 33, Third Edition, American Petroleum Institute, Washington, D.C.

ANSI, 1980, *American National Standard Calibration and Usage of Sodium Iodine Detector Systems*, ANSI N4212-1980, American National Standards Institute, New York, New York.

WHC-SD-EN-TI-292, *Calibration of the Radionuclide Logging System Germanium Detector*, Westinghouse Hanford Company, Richland, Washington.

WHC-SD-EN-TI-293, *Procedures for Calibrating Scintillation Gamma-Ray Well Logging Tools*, Westinghouse Hanford Company, Richland, Washington.

8.0 REFERENCES

HNF-PRO-453, *Environmental Notification and Reporting*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-454, *Inactive Waste Sites*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-455, *Solid Waste Management*, Fluor Daniel Hanford, Inc., Richland, Washington.

HNF-PRO-505, *Health Physics Procedures Manual, Appendix I*, Fluor Daniel Hanford, Inc., Richland, Washington.

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ATTACHMENT A. SPECTRAL GAMMA-RAY LOG ANALYSIS PROCEDURE.

1.0 APPLICABILITY

This attachment describes the minimum technical requirements for borehole spectral gamma-ray log analysis to be performed by WMNW. Spectral gamma-ray log results may be used to:

1. Provide nondestructive, in-situ assays of gamma-ray-emitting nuclides that are present in subsurface strata (using spectral gamma instrumentation).

2. Delineate and characterize subsurface lithology (i.e., natural KUT) for use by geologist.

2.0 DEFINITIONS

2.1 PERSONNEL RESPONSIBILITIES

The log analyst, or a log analysis technician, operates the log analysis software, ensures that the log data reduction is performed properly, prepares the log analysis survey results files, and ensures that the analyzed log data results are transferred to a permanent mass-storage medium.

3.0 PROCEDURES

Gamma-ray emissions measured by the HPGe detectors at multiple depth locations within a borehole are spectral surveys which are analyzed by software programs designed for the purpose. The LGCALC program is one such program (Ulbricht et. al. 1993) and has been independently verified (Stromswold 1994). The LGCALC program was developed for analysis of high resolution germanium spectra acquired during borehole surveys and resolves deficiencies encountered in the commercially available software available at the time. The program was developed by Westinghouse Hanford Company (WHC) Geophysics Group for use at Hanford and each revision is archived on digital archive cartridges. The program was re-assigned to WMNW for continued use in borehole geophysics.

The main functions performed by the LGCALC program and the steps the analyst must perform are described here.

3.1 ANALYSIS OF LOG SURVEY DATA

The steps to analyze the borehole survey spectra for identification of gamma-ray emitting radionuclides present, compute their concentrations, and produce the three components of the log survey results (i.e., Survey Header Sheet, Survey Report, Survey Data Plots) are summarized as follows.

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Review the Borehole Survey Data Sheet(s) for the borehole to be analyzed. Particular interest is given to:

a. Well ID in order to locate and review the well as-build summary sheet for casing depth intervals and perforation zones,

b. Instrument Calibration Configuration to verify the proper calibration coefficients are present in the efficiency file (EFFIC.FIL),

c. Water depth,

d. Casing sizes, thickness, and material,

e. File name prefix,

f. Log survey verification measurements,

g. Log survey intervals, and

h. Logging technician notes.

The Borehole Survey - Data Analysis Form (see Figure 1) is completed concurrent with the processing of each borehole analyzed. Only one analysis form is required even if multiple log survey sessions were required to complete the collection of log data for a borehole.

Copy raw survey data files from the archive media to the hard disk of an analysis computer.

Run the LOGSUM program with the FIELD batch file to generate an ASCII file (0GROSS2.DAT) of survey depth and gross detector count rate and ASCII file (0GROSS1.DAT) of the borehole number, survey date, depth interval. These files are imported into the (FIELD.SPW) plot template of Sigma Plot. Examine the plot for unusual conditions (i.e., instrument response characteristics, borehole environment, geologic strata, and intervals of potential unusual radioactivity.

Examine several spectra files with the Gamma Vision[1] or equivalent spectra examination software to check energy calibration coefficients and identify the radionuclides most prominent in the borehole.

Edit the radionuclide analysis library (NUCLIDES.FIL, an ASCII file) to select the radionuclide(s) which will be the target of the LGCALC analysis. The library contains the gamma-ray energy(s) used to identify each radionuclide and the percentage of time the identifying gamma ray is emitted per 100 decays. The file contains comment records to provide additional assistance to the analyst. The first parameter of a radio-isotope record (up to 8 characters) is the name that is assigned to the output results file (-.PKS extension.) The order of the radioisotope records in the file directs the order in

[1]Gamma Vision is a trademark of EG&G Ortec.

which LGCALC associates (matches) gamma-ray peaks to the radioisotopes.

An input processing control file (INP.TMP, an ASCII file) contains the name of each spectra file to be analyzed by LGCALC. The file is created by the "MATCH *.CHN INP.TMP" program which requires two run string parameters. The first spectra file name in the processing control file is used by LGCALC to initialize the automatic energy re-calibration algorithm (described in Attachment B.)

Execute LGCALC. The analysis control parameters entered on the input screen include: casing or hole diameter, thickness, and depth interval. The electron density of the attenuating material is used by the program algorithm (i.e., density of steel–7.325, water–1.11). After the processing control parameters are entered and verified, program execution is begun by pressing the [F10] function key. The control parameters are saved in a file associated with the borehole survey and is used to reinitialize the program with subsequent executions (LGCALC.INP is an ASCII file.) The program creates several ASCII files that constitute the analysis results. The LGCALC program algorithms and output file contents are described in Attachment B.

Examine the LGCALC analysis results files to verify the program properly identified the gamma-ray peak energy, the nuclides retrieved from the nuclide library, the casing and water correction factors, and the computed activity of each radionuclide are correct. If errors occur, identify the cause, make the appropriate correction and re-execute LGCALC. The decay activity of the natural radionuclides are reviewed for consistency of the concentrations in adjacent boreholes.) Significant differences in the computed activity of the natural radionuclides; i.e., potassium, uranium, and thorium, may indicate borehole conditions different from the as-built records used for analysis.

Once the computed results are accepted by the analyst, the LGCALC results files must be prepared for input into the graphing software Sigma Plot[2] by running the TOPLOT program. The TOPLOT program is used to reformat the LGCALC results for simplified input into the appropriate plot templates. Additionally the Survey Header page and Survey Report page are generated by word processing software.

Complete the Borehole Survey - Data Analysis Form, prepare the document folder containing the paper results for inclusion into the file archive, prepare the electronic files for insertion on to the archival media.

3.2 LOG HEADER, SURVEY REPORT, AND BOREHOLE SURVEY - DATA ANALYSIS FORM DOCUMENTATION

The Borehole Survey - Data Analysis Form is used to record pertinent information for each analysis conducted. This data analysis form is the basis from which the Log Header and Survey

[2]Sigma Plot is a trademark of Jandel Scientific.

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Report is prepared. Completion of the Borehole Survey - Data Analysis Form shall be in accordance with the following specifications.

1. If a particular data field is not applicable to a particular log analysis, indicate by entering N/A in that field.

2. Make all log data entries with permanent black ink.

3. Line out corrections with a single line and place the correct entry as close as possible to the incorrect one. Initial and date the correction.

4. The Borehole Survey - Data Analysis Form shall be signed and dated by the analyst entering the information.

3.3 RECORDS DISPOSITION

When log analysis is completed, check the Borehole Survey - Data Analysis Form, Log Header, Survey Report, and each Log Plot to ensure that:

1. All information is entered, legible and correct.

2. Abnormalities, observations, and adjustments are recorded on the Survey Report and other documents as appropriate.

3. Name, signature and date are recorded.

The Log Analyst processes the log analysis results sheets and electronic results files as specified in Section 6.0 (Records). The archival disk will be retained in the archival files as specified in Section 3.6 (Log Analysis). A copy of the analysis results files will be made on a second disk. This disk will be retained in Geophysics' Investigations' files. The files will be secured (locked), will be under fire protection conditions, and will have controlled access. As disks are filled, duplicate disks will be processed as described in Section 6.0 (Records).

3.4 REFERENCES

Ulbricht, W. H., R. E. Engelman, D. C. Stromswold, 1993, *Alternatives Evaluation for Spectral Gamma-Ray Data Analysis Software*, WHC-SD-WM-TA-149, Westinghouse Hanford Company, Richland, Washington.

Stromswold, D. C., 1994, *Technical Evaluation of Software for Gamma-Ray Logging System*, PNL-9807, Pacific Northwest Laboratory, Richland, Washington.

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ATTACHMENT B. SPECTRAL GAMMA-RAY LOG ANALYSIS ALGORITHM AND FILE FORMATS.

1.0 ANALYSIS ALGORITHM

The analysis algorithm of LGCALC is composed of several sub-algorithms that are performed on each survey spectra that compose the borehole survey. Repeat survey spectra are processed with the same routine as the main log. The sub-algorithms are as follows.

Verify the energy calibration coefficients are consistent with the gamma-ray peaks present in the spectra. This program step (sub algorithm) is performed by attempting to locate six commonly present gamma-ray peaks in the spectra (583, 609, 661, 1461, 1765, and 2614 KeV). If at least one of these peaks is well defined the program will adjust the gain of the energy calibration toward the location of the photo peak. The program searches with in a limited energy window (± 20 KeV for photo peaks < 1000 KeV) for a well-defined peak. If the photo peak energy is less than 1500 KeV the location of the new peak must be within 3 channels of the previously accepted peak. A well-defined peak is one whose peak count rate is five times above the average background count rate. Adjustments to the energy calibration are performed only on the "gain" coefficient of the energy calibration. The adjustments are half steps between the computed new gain and the present gain setting. The analyst can over-ride the automatic program operation for one spectra and force the energy calibration to be reset to the energy coefficients coded in a spectra by entering the key word "RECAL" as the second parameter on the selected spectra name record in the INP.TMP file. A nominal drift during the borehole survey in the channel location of gamma-ray peaks is due to minor drift during the first 24 hours in the electronics modules when electrical power is first applied. This problem is avoided in the laboratory setting since electrical power is applied continuously.

Locate all gamma-ray photo peaks present in the spectra and determine the net count rate (using live time, LT.) The algorithm was developed to locate all peaks such that no gamma-ray photo peak should be missed. However, this algorithm occasionally permits some channels with statistically elevated counts to be identified as a possible gamma-ray peak. The program constructs a background average from 10 spectra channels (6 KeV window width, approx.) then searches ahead of the temporary background window for any channel whose counts are greater than 3 sigma (99.5% confidence interval) above the threshold. The search is conducted for 30 channels. If no channels are identified with a count that exceeds the threshold, the background window is advanced by 10 channels, the background is recomputed, and the search loop continues. This algorithm assures that the counts in each channel will be examined by three background averages and that essentially no gamma-ray photo peaks will be undetected. If the background threshold value is less than 2 counts then the program sets the threshold to a minimum of 2 counts to identify a photo peak, this condition frequently occurs at energies above 1500 KeV. The extent (net area) of a gamma-ray photo peak is discussed next.

The temporary (preliminary) width of a gamma-ray peak is set to include all spectra channels whose count exceed the background threshold limit (defined above). Then the program begins an iterative process to compute the average background below (lower energy) the peak by computing the average from 10 spectra channels. If the highest channel count in the background window is the channel adjacent to the photo peak then this high channel is added to the photo peak, the background window is re-adjusted and the average background is re-computed. The routine continues this

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iteration until the highest channel count in the background window is not adjacent to the photo peak. The program duplicates this logic to compute the average background above (higher energy) the peak. This sub-algorithm is able to efficiently adjust the number of channels that define a gamma-ray peak to the data present in the spectra, will locate poorly shaped peaks, and has proven superior for processing spectra from HPGe detectors with less than ideal resolution.

The net area of a gamma-ray peak is computed by summing the counts of all channels that define the peak then subtracting the average background. The average background subtracted from the gross peak area is the average of the low and high energy backgrounds times the number of channels that define the peak. The count rate of the gamma-ray peak is computed by dividing the net counts by the live time (LT) of the spectra. The LGCALC program has a debug option (input parameters on the analyst input screen) that directs the program to record in LGCALC.DBG (an ASCII file) the various details of the program logic (i.e., peak start/stop channel numbers, channel counts, backgrounds.) The uncertainty of the net peak count rate is computed with the equation:

$$UncCPS = \sqrt{\frac{\sum Pkcnt + \left(\sum BgLo + \sum BgHi\right) * X}{LT}}$$

$$X = \frac{nPkChan}{\left(2 * nBgChan\right)^2}$$

Where:	UncCPS	net peak count rate uncertainty (1 sigma)
	Σpkcnt	sum of gross channel counts of a gamma ray peak
	ΣbgLo	sum of channel counts for the low energy background
	ΣbgHi	sum of channel counts for the high energy background
	LT	spectra collection time (Live Time) in seconds
	nPkChan	number of channels that define the gamma ray peak
	nBgChan	number of channels that define a background window

The gamma-ray peaks identified in the spectra are compared with the radionuclides selected by the analyst in the NUCLIDES.FIL. A match between the spectra peak and the library peak is made if the energies agree within a certain limit. The gamma-ray peak match limit increases at a linear rate of 5 KeV per 1000 KeV with a minimum acceptable match limit of 5 KeV. After a match is established between the spectra gamma-rays and the library gamma-rays, the spectra peaks that did not match with a library gamma-ray are re-examined to determine if they should be reported in the NONMATCH.PKS file. An un-matched peak is reported in the LGCALC.DBG and NONMATCH.PKS files if the net counts is three times greater than the average background counts. The un-matched peak is reported in NONMATCH.PKS as a pseudo graphical form as a single numeric digit. The scale factor of single numeric digit that represents the peak intensity is the square root of the number of times the net peak counts exceeds five times the average background counts. If the single numeric digit is greater than 9 then an asterisk "*" is printed in the NONMATCH.PKS record, if the digit is less than 1 then a period "." is printed.

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The radionuclide concentration (pCi/g) is computed from the net count rate of each gamma-ray peak identified in the NUCLIDES.FIL file and is corrected for attenuation from borehole fluid (water inside the casing) and casing thickness. The calibrated detector efficiency, with calibration data, is recorded in the EFFIC.FIL (ASCII format) file. The equations used to compute the casing and water attenuation factors and detector efficiency (count rate to pCi/g conversion factor) for each gamma-ray energy are:

$$Y = 4.584 * Energy^{-0.46292} * Thk * Den$$

$$CasCor = Por + (1 - Por) * e^{Y}$$

Where:	Energy	energy of the gamma-ray (KeV)
	Thk	thickness of attenuating material (inch)
	Den	electron density, g/cc (steel=7.325, water=1.11)
	Por	porosity of attenuating material, % (i.e., casing screen, 0=solid)
	CasCor	gamma-ray correction factor for attenuating material

The equation used to compute the detector efficiency (count rate to pCi/g conversion factor) for each gamma-ray energy is:

$$FE = \frac{A * Energy^{AA} + B * Energy^{BB}}{XN}$$

$$Conc = NetCPS * CasCor * FE$$

$$UncConc = \frac{UncCPS * CasCor * FE}{Conc * 100}$$

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Where: FE	detector efficiency factor for a gamma-ray peak (pCi/g/cps)
Energy	energy of the gamma-ray (KeV)
A,AA,B,BB	coefficients defined on the calibration certificate
XN	number of gamma-ray emissions per 100 decays (percent)
Conc	radionuclide concentration (pCi/g)
UncConc	uncertainty in radionuclide concentration (1 sigma, percent)

2.0 LGCALC FILES

The input and output files for the LGCALC program are described below.

LGCALC.SCN input file that defines the initial defaults and key-word name of each input screen parameter.

LGCALC.INP: The program initialization parameters are stored in an ASCII file in the directory of each log survey analyzed. The file contains the name of the input control file, the parameters for computing the gamma-ray attenuation, and the program debug option level. An example of the file follows. LGCALC accepts operator changes on the screen form, save analysis control parameters to the LGCALC.INP file for re-initialization on subsequent executions.

```
MFINP=INP.TMP
ROW1=6,.25,7.32,0,0,249
ROW2=8,.33,7.32,0,0,123
ROW3=,,,,,
ROW4=,,,,,
ROW5=,,,,,
ROW6=,,,,,
DBUG=1
```

Read the NUCLIDES.FIL library. The library supplies the nuclide name, the identifying gamma-ray energies (keV), and gamma-ray intensity (percent). The NUCLIDES.FIL is copied to the sub-directory of each log survey being analyzed and is the copy used for subsequent executions of LGCALC. An example of the file follows.

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```
*  File:   \PROGRAM\NUCLIDES.FIL
*          Records begining with an asterisk "*" are comments
*
* Density of steel = 7.32 g/cc
*
* File control records have the radionuclide name as the first parameter
* then the gamma-ray energy (KeV) and
* percent of gamma-ray emissions per 100 decays
*
 K40,1461=10.7
* CO60,1173=99.9,1333=100
 CS137,662=84.6
* EU154,123=40.5,723=19.7,873=11.3,996=10.7,1005=17.6,1274=35.5
* U238,1001=0.59,767=0.21
* U235, 144=10.5,163=4.7, 186=54,  205=4.7
* PU239,99=0.0042,129=0.0062,414=0.0015
* PU240,104=0.007,160=0.0004
* AM241,60=36.3,99=0.029,103=0.032,125=0.0059,208=0.0016,335=0.0011
* PA233,300=5.8,312=33.7,340=3.9,398=1.3
* PA233;T1/2=27.4Days, Parent=Np237 2.14E6yr
* THORIUM, 2615=35.8
 THORIUM, 583=30.8,727=11.8, 911=29,  969=17.5, 2615=35.8
* THORIUM,238=44.6,583=30.8,727=11.8, 911=29,  969=17.5, 2615=35.8
* URANIUM,609=46.1
 URANIUM,295=19.2,352=37.1,609=46.1,1764=15.9,1120=15.0
* URANIUM,241=7.5, 295=19.2,352=37.1,609=46.1,1764=15.9,1120=15.0
* SB125,176=6.3, 381=1.4,428=29.6,464=10,  601=18.4,  607=5.2,  636=11.2
* EU152,122=29.2,344=27, 779=13,  964=14.6,1086=10.3, 1112=13.6,1408=21.2
*
*  Contents: Gamma-ray energy and intensity table
*       Energy preceeds equal sign "=";  Intensity (pct) follows "="
*       Gamma ray energy used only for photo-peak identification,
*        not used for spectra channel to energy calibration.
*       First parameter of record is radionuclide name
*
*  Gamma-ray intensities: "Gamma Rays of Radionuclides" Erdtmann/Soyka
*
*  Notes of explanation
*    U-238   Uses Pa-234 as gamma-emitting isotope (2nd daughter of U-238)
*    Uranium indicates natural environment, secular equilibrium
*            Gamma-rays from Bi-214, Pb-214  used for concentration
*            186=Ra-226   241=Pb-214     295=Pb-214      352=Pb-214,Bi-211
*            609=Bi-214  1120=Bi-214   1764=Bi-214
*    Thorium indicates natural environment, secular equilibrium
*            Gamma-rays from Ac-228, Pb-212, Bi-212, Tl-208 used
*            Tl-208 gamma-ray intensity adjusted for Bi-212 branching
*             ratio (35.8%) to Tl-208 and Po-212 (64.2%)
*            238=Pb-212,Ra-224 583=Tl-208      727=Bi-212       860=Tl-208
*            911=Ac-228        969=Ac-228    2614=Tl-208
*
*  Peak match order: Order of nuclides in table.
*      Except Nuclides with only 1 Gamma-ray are moved to end of table
*
*END
```

EFFIC.FIL: The calibration coefficients for each spectral gamma-ray detector are maintained in the EFFIC.FIL (an ASCII file.) An example of the file follows. The file contains the probe name, calibration date, outside diameter for the water attenuation correction, equation type of the efficiency function, valid energy limits, and efficiency equation coefficients. ALIAS records are present that permits multiple probe names (logging technician entry problems) to be assigned the same calibration coefficients.

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```
* EFFIC,FIL = Detector Efficiency Calibration Coefficients
*
* Comment records contain an asterisk "*" in column 1
*
* ALIAS records contain temporary name, followed by permanent name
* ALIAS HPGE2=RLS2.2
*
* PROBE Name,   Date,    Equation-type, Sonde-diam, Low-KeV, Hi-KeV
* PROBE RLS2.2, 15MAR94, RUSS,          3.88,       150,     3000
*  Equation-type "RUSS" as per Aug26, 94 report
*  Equation-type "KOIZUMI" as per 92 report
*
* COEFF are the coefficients of the calibration function
* COEFF A, AA, B, BB, ...
*
*RLSG5=10%,HIGH COUNT RATE W/ TUNGSTEN SHIELDING
*RLSG4=70%,SINGLE DETECTOR (SLIM) HOUSING, TRUCK RLS-2
*RLSG3=35%,DUAL DETECTOR FOR TRUCK RLS-2
*RLSG1=18%,SINGLE DETECTOR IN LONG (DUAL DETECTOR HOUSING)
*          NaI DETECTOR IN HOUSING FROM NOV90 THRU NOV91
*
ALIAS RLSG2.2=RLS2.2
ALIAS HPGE-18%=RLSG1
ALIAS HPGE 18%=RLSG1
ALIAS RLSG-1=RLSG1
*
*
PROBE,RLSG5.1,9JUL96,RUSS,3.88,300,3000
COEF 16.02,0.326 , 1.286E8,-2.166
*
PROBE,RLSG5.0,10NOV95,RUSS,3.88,240,3000
COEFF 7.56 ,0.419  , 1.108E8, -2.13
*
PROBE,RLSG4.1,17FEB95,RUSS,3.88, 150,3000
COEFF 5.006,0.2206, 0,0
*
PROBE,RLSG4.2,27MAR95,RUSS,3.88,150,3000
COEF 8.091,0.1317, 0,0
*
* RLSG3.1 IS FOR TRUCK#1
PROBE,RLSG3.1,30MAY96,RUSS,3.62, 150,3000
COEFF 8.1605,0.22390, 0,0
*
PROBE,RLSG3.0,24MAY96,RUSS,3.62, 150,3000
COEFF 7.8288,0.22701, 0,0
*
PROBE,RLSG3.0,22MAR95,RUSS,3.62, 150,3000
COEFF 8.14249,0.22126, 0,0
*
PROBE,RLS3,13MAY94,RUSS,3.88, 150,3000
COEFF 6.47075,0.41529, 0,0
*
PROBE,RLS2.2,04APR94,RUSS,3.88, 70,3000
COEFF 10.516,0.32325, 2.36E10,-4.217
*
PROBE,RLSG1, 31MAR93,RUSS,3.88, 150,3000
COEFF 9.976,0.34007, 0,0
*
PROBE,RLSG1, 30NOV91,RUSS,3.88, 150,3000
COEFF 7.738,0.37106, 0,0
*
PROBE,RLSG1, 28NOV90,RUSS,3.88, 150,3000
COEFF 8.9066,0.36373,0, 0
*
```

INP.TMP: The LGCALC input processing control file contains names of each spectra file being processed. The energy calibration coefficients can be reset by adding the "RECAL" as the second parameter of the appropriate file name record. An example of the file follows.

26-0039779 LMIT

```
B0241000.CHN
B0241001.CHN
B0241002.CHN
B0241003.CHN,  RECAL
B0241004.CHN
B0241005.CHN
B0241006.CHN
B0241007.CHN
B0241008.CHN
B0241009.CHN
B0241010.CHN
B0241011.CHN
B0241012.CHN
```

Analysis output files: The specifications in the NUCLIDES.FIL library controls the number of analysis output files created by LGCALC. An analysis output file is created for each radionuclide that has multiple gamma-ray energies. The radionuclides with a single gamma-ray energy are output to the MONO.PKS file, followed by the reported concentration for each radionuclide with multiple gamma-rays, and the gross detector count rate. All files are composed of ASCII characters requiring no special conversion to be printed.

CO60.PKS: A radionuclide with multiple gamma-rays contains the computed concentration for each gamma-ray present in the spectra. The file name is composed of the nuclide name (8 characters maximum with no embedded special characters) and the file name extension of ".PKS". The file contains two record types. The first record contains the borehole number, nuclide name, and each gamma-ray energy retrieved from the library. The second record type contains the depth, spectra file sequence number, and computed decay activity and uncertainty (pct, 1 sigma) for each gamma-ray identified in the spectra file belonging to this radionuclide. One record is created for each spectra where at least one gamma-ray peak is identified in the channel data. If multiple gamma-ray peaks belonging to the radionuclide are identified the program selects the one with the lowest uncertainty to be reported as the nuclide decay activity in the summary file "MONO.PKS". An example of a radionuclide with multiple gamma-ray peaks follows.

```
299-W30-099,CO60,1173      ,1333
 1.01 000 , 282.3,0.6, 247.9,0.6
 1.51 001 , 321.8,0.5, 287.0,0.5
 2.01 002 , 349.8,0.4, 309.4,0.5
 2.51 003 , 368.4,0.4, 327.9,0.4
 3.01 004 , 383.3,0.4, 343.4,0.4
 3.51 005 , 395.6,0.4, 352.6,0.4
 4.01 006 , 405.1,0.3, 360.4,0.4
 4.51 007 , 412.8,0.3, 363.9,0.4
 5.01 008 , 416.3,0.3, 371.2,0.3
 5.51 009 , 421.5,0.3, 373.5,0.3
 6.02 010 , 70.45,3.9, 66.11,4.1
 6.52 011 , 147.4,1.7, 130.7,1.8
 7.02 012 , 206.8,1.0, 190.9,1.0
```

MONO.PKS File: The radionuclide decay activities computed from each spectral gamma-ray survey file is compiled and written to the output file MONO.PKS. The file contains two record types. The first record contains the borehole number and name of each radionuclide supplied by the NUCLIDES.FIL library. The second record type contains the depth, computed decay activity for each radionuclide and uncertainty (pct, 1 sigma), the spectra file sequence number, the dead-time (pct), and total gamma-ray activity in counts-per-second. One record, type two, is created for each spectra analyzed. If no gamma-ray peaks for a radionuclide were identified in the spectra then the associated column is left blank. A zero value is not reported. An example of a MONO.PKS file follows.

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```
299-W30-099,K40,   CS137,        THORIUM,   URANIUM,   CO60
 1.01,        ,    ,1069.7,0.3,        ,    , 142.9,1.3, 282.3,0.6  ,000 ,44,   54206
 1.51,  0.58, 31,1230.3,0.2,  0.08, 40, 82.08,1.6, 321.8,0.5  ,001 ,35,   42036
 2.01,  0.30, 36,1320.5,0.2,  0.11, 35, 58.83,1.9, 349.8,0.4  ,002 ,31,   35303
 2.51,  1.86, 12,1393.5,0.2,  0.11, 32, 39.79,2.2, 368.4,0.4  ,003 ,26,   29796
 3.01,  2.08, 11,1454.1,0.2,  0.33, 16, 25.32,2.4, 383.3,0.4  ,004 ,23,   25616
 3.51,  2.56,8.8,1502.5,0.2,  0.48, 12, 19.83,3.2, 395.6,0.4  ,005 ,21,   22489
 4.01,  2.22,8.7,1531.9,0.2,  0.31, 15, 13.35,3.7, 405.1,0.3  ,006 ,18,   19924
 4.51,  2.86,6.5,1556.7,0.2,  0.51, 11, 10.54,4.4, 412.8,0.3  ,007 ,17,   18147
 5.01,  2.19,7.8,1576.4,0.2,  0.50, 11,  7.23,5.5, 416.3,0.3  ,008 ,16,   16787
 5.51,  2.13,7.1,1587.2,0.2,  0.36, 13,  6.74,5.7, 421.5,0.3  ,009 ,15,   15699
 6.02,      ,   , 337.4,1.6,        ,   , 357.6,1.4, 70.45,3.9  ,010 ,75,  108533
 6.52,      ,   , 607.4,0.8,        ,   , 328.8,1.2, 147.4,1.7  ,011 ,64,   88495
 7.02,      ,   , 824.8,0.5,  0.16, 39, 236.3,1.2, 206.8,1.0  ,012 ,55,   71631
```

NONMATCH.PKS File: Gamma-ray peaks located in the spectra that were not associated with a radionuclide supplied by the NUCLIDES.FIL library are represented semi-graphically in the NONMATCH.PKS output file. The file contains two record types. The first record contains the borehole number and energy scale from 0 to 3000 KeV with each character position representing 50 KeV. The second record type contains the spectra file name, depth, and a multiple sets of single digits (., 0-9. *) that represent the magnitude that the non-matched gamma-ray peak exceeds the average spectra background. One record, type two, is created for each spectrum containing gamma-ray peaks not identified with a library radionuclide. An example of a NONMATCH.PKS file follows.

```
299-W30-099    |0  . . . .5  . .  1.0  . .  1.5  . .  2.0  . .  2.5  . .  3.|
B0241000   1.0 |                     1 1  .      131     1 3.  2 2          |
B0241001   1.5 |                     1 1  .  .   131     1 3   2 3          |
B0241002   2.0 |                     1 .  .  .   131     1 3.  3 4          |
B0241003   2.5 |                     1 .  .      131     1 3   2 4          |
B0241004   3.0 |                     1 .  .      131  .  1 2   2 5          |
B0241005   3.5 |                     . .  .  .   131     1 2   2 6  1       |
B0241006   4.0 |                     . .         131  1  1 2   2 8          |
B0241007   4.5 |                          .      12.  1  1 2   2 6          |
B0241008   5.0 |                                 12   1  . 2   2 8  1 1     |
B0241009   5.5 |                                 .2.  1    1   2 .  1       |
B0241010   6.0 |      .              1            1        1                |
B0241011   6.5 |      .              1 .         .2.       2   1 .          |
B0241012   7.0 |                     1 1  1.     121     12    1 1          |
```

LGCALC.DBG File: A detailed program operation report is written to the LGCALC.DBG output file. An example of the LGCALC.DBG file is presented in the following figure. Several record types are present in the file whose contents include:

> ">>>>> LT" record is the first record printed for each spectra file. It contains the spectra live time (seconds), file name and depth in the borehole. The record format is designed to easily locate the information for a particular spectra file.
>
> "I, J, E 1 8 1461. Corrections, FACT, ALL" record contains the attenuation correction factors, detector conversion efficiency (c/s to pCi/g), and combined conversion factor by multiplying both factors together for each gamma-ray identified in the NUCLIDES.FIL library. A set of correction factor records are reported at each change in borehole conditions (i.e. water, casing thickness.)

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****** NEW ENERGY CALIBRATION BASIS SET ****** record reports that the energy calibration algorithm has been initialized. The following record ("NCal" in the third parameter) reports energy calibration coefficients present in the spectra file, the calibration gain coefficient used by LGCALC, and the well-defined gamma-ray peaks identified in the spectra that were used to adjust the energy gain calibration coefficient.

"Peaks keV" record reports all gamma-ray peaks identified by LGCALC in the spectra file.

"# Chan, Cnt" record reports the details for all non-matched gamma-rays with measurement uncertainty less than 50%. The record contains the peak channel number, net counts, count rate, uncertainty (%), and gamma-ray energy (KeV).

```
>>>>> LT 169.26                                        B0241000.CHN        1.0<<<<<
 I,J,E 1 1 1173. Corrections,FACT,ALL   1.000  1.000  1.0000
 I,J,E 2 1 1333. Corrections,FACT,ALL   1.000  1.000  1.0000
 I,J,E 1 8 1461. Corrections,FACT,ALL   1.000  1.000  1.0000
 I,J,E 2 8  662. Corrections,FACT,ALL   1.000  1.000  1.0000
 I,J,E 3 8 2615. Corrections,FACT,ALL   1.000  1.000  1.0000
 I,J,E 4 8  609. Corrections,FACT,ALL   1.000  1.000  1.0000
 ***** NEW ENERGY CALIBRATION BASIS SET *****
 .690 -9.6 NCal .690 Pks   0=   0.  0.    0=   0.  0. 00
Peaks keV  295  352  511  608  661  701  766  805  837  932 1118 1154 1171 1206
Peaks keV 1236 1278 1330 1375 1400 1507 1581 1660 1727 1762 1835 1845 2081 2116
Peaks keV 2201 2291 2444 2502 2729
  1 Chan,Cnt  441    4270. CPS  25.230   7.0 * KEV                  295
  2 Chan,Cnt  524   10944. CPS  64.656   3.2 * KEV                  352
  3 Chan,Cnt  755    1048. CPS   6.189  13.0 * KEV                  511
 10 Chan,Cnt 1365    1991. CPS  11.763   7.1 * KEV                  932
 11 Chan,Cnt 1634   11588. CPS  68.462   1.7 * KEV                 1118
 15 Chan,Cnt 1805    4940. CPS  29.187   2.9 * KEV                 1236
 20 Chan,Cnt 2198    1689. CPS   9.981   5.7 * KEV                 1507
 23 Chan,Cnt 2517    2929. CPS  17.303   3.4 * KEV                 1727
 24 Chan,Cnt 2568   17253. CPS 101.933   1.0 * KEV                 1762
 26 Chan,Cnt 2688    1673. CPS   9.883   4.3 * KEV                 1845
 28 Chan,Cnt 3081    1195. CPS   7.060   5.0 * KEV                 2116
 29 Chan,Cnt 3204    5846. CPS  34.536   1.7 * KEV                 2201
 >>>>> LT 194.26                                        B0241001.CHN        1.5<<<<<
 .690 -9.6 NCal .690 Pks   0=   0.  0.    0=   0.  0. 00
Peaks keV  352  511  608  661  705  767  805  932 1118 1153 1171 1236 1279 1306
Peaks keV 1331 1375 1400 1458 1507 1582 1659 1727 1763 1833 1845 1870 1987 2116
Peaks keV 2201 2266 2286 2444 2502 2613 2697
  1 Chan,Cnt  524    7443. CPS  38.315   3.9 * KEV                  352
  2 Chan,Cnt  755     986. CPS   5.078  12.9 * KEV                  511
  6 Chan,Cnt 1126    2024. CPS  10.417   7.1 * KEV                  767
  7 Chan,Cnt 1181     248. CPS   1.274  24.9 * KEV                  805
  9 Chan,Cnt 1634    9080. CPS  46.744   1.9 * KEV                 1118
 12 Chan,Cnt 1805    3835. CPS  19.742   3.2 * KEV                 1236
 16 Chan,Cnt 2007    2494. CPS  12.836   3.8 * KEV                 1375
 22 Chan,Cnt 2517    2680. CPS  13.797   3.2 * KEV                 1727
 23 Chan,Cnt 2569   14876. CPS  76.578   1.0 * KEV                 1763
 25 Chan,Cnt 2688    1520. CPS   7.824   4.1 * KEV                 1845
 29 Chan,Cnt 3204    5280. CPS  27.181   1.7 * KEV                 2201
 >>>>> LT 208.16                                        B0241002.CHN        2.0<<<<<
 .690 -9.6 NCal .690 Pks   0=   0.  0.    0=   0.  0. 00
Peaks keV  296  352  510  609  661  741  767  785  804  934 1118 1153 1171 1236
Peaks keV 1280 1331 1375 1406 1458 1507 1581 1659 1727 1763 1833 1845 1903 1991
Peaks keV 2116 2165 2201 2290 2419 2444 2502 2549 2611 2692
  1 Chan,Cnt  443     794. CPS   3.813  14.7 * KEV                  296
  2 Chan,Cnt  524    4438. CPS  21.319   5.3 * KEV                  352
  3 Chan,Cnt  753    1505. CPS   7.231  12.1 * KEV                  510
```

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ATTACHMENT C. MINIMUM DETECTION LIMITS FOR
RLS HPGe LOGGING SYSTEM.

1.0 BACKGROUND

The RLS uses an HPGe detector housed in a borehole logging sonde. The high resolution detector signals are processed by truck mounted spectra processing electronics and are recorded on a truck mounted computer for subsequent analysis.

The data analysis is performed to identify the radionuclide(s) present and compute their concentration. The radionuclide concentration is computed from full energy gamma rays that are captured by the HPGe detector. The gamma rays scattered down from their initial energies create a continuum above which the full energy gamma ray must extend. The purpose of this discussion is to define and quantify the minimum detection limit (MDL) of the borehole measurements. The quantification of the MDL is complex and will be briefly explored.

Figure 1 shows an actual field collected spectra, where the dominant radio-isotope was Co-60. Co-60 produces two gamma rays with energies of 1173 and 1333 keV. Notice also the continuum labeled Compton background. The Compton background represents all scattered gamma rays (loss of energy) emitted from all sources (both Co-60 and the natural radionuclides of K, U Th in this example). The gamma ray photo peaks are summed with this Compton background (which can be more easily seen for the 1173 keV gamma ray). Therefore, the determination of the photo peak intensity requires a background subtraction.

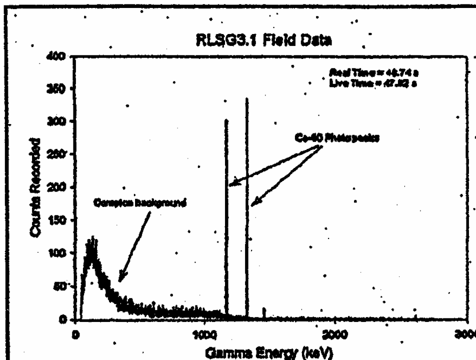

Figure 1. Field example from the 35% HPGe logging tool at a depth where Co-60 is present.

2.0 MINIMUM DETECTION LIMIT

The working definition for minimum detection limit is:

> The minimum net photo peak intensity for which a reliable presence exists for the parent radionuclide.

Since the net photo peak intensity is the desired objective, the consistent detection of its presence at the lowest levels possible is a function of the signal to noise (i.e., Compton background.) The noise in this case is the Compton background above which the gamma ray photo peak must extend or is summed with. There are several variables that affect this signal to noise factor.

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2.1 PRECISION (REPEATABILITY) OF THE COMPTON BACKGROUND

The precision for quantifying the Compton background is a function of the algorithm used to measure the background adjacent to the photo peak (region of interest [ROI]). Also, the level (slope) of the background influences the precision of assessing the background intensity (magnitude). In general, the higher the background intensity, the higher the photo peak intensity must be in order to detect the photo peak, which increases the MDL.

The analysis algorithms used by WMNW incorporates a standard method of computing background intensity. The background is measured in two windows, one below (lower energy) and one above (higher energy) the region of interest of the gamma ray photo peak. The width of these background windows is 10 channels (approximately 7 keV.) These wider windows yield improved precision of background continuum and therefore lower MDL's. Increasing the background window widths cannot be made arbitrarily large for two reasons: 1) possible interference from adjacent photo peaks that would void the background calculation, and 2) variations of the Compton background occur as a function of energy and therefore, the background windows must be kept near the ROI that the background is to be projected into.

2.2 IMPROVED DETECTOR RESOLUTION

Generally, the better the energy resolution capability of a detector will improve (lower) the MDL. An increased energy resolution means that the gamma ray photo peak is contained (defined) in fewer spectra channels while maintaining a low Compton background. The result is an improved signal to nearly constant noise factor. Clearly, analysis algorithms that establish the smallest possible ROI while providing a fully resolved photo peak will produce lower MDL's. The analysis algorithms used by WMNW (see Attachment B), does have a self adjusting window for the photo peak ROI.

2.3 THE CONCENTRATION OF OTHER RADIONUCLIDES

The presence of other gamma emitting radioisotopes interferes by increasing the Compton background, especially for low energy gamma ray photo peaks. Note in Figure 1 that the Compton background from the Co-60 source is much higher in the region of 661 keV, than if there were no Co-60 present. Therefore, in this particular example, the MDL for Cs-137 (661 keV), would be increased by the presence of the Co-60, some times substantially. Also, in some cases, the presence of high energy beta emitting radionuclides, such as Sr-90, can increase the background continuum (i.e., Bremsstrahlung radiation) which also increases the MDL.

2.4 BOREHOLE CASING AND WATER

The photo peak attenuation from shielding materials between the detector and source radionuclides both decreases the signal (gamma ray photo peaks) and increases the Compton background (noise). The most common shielding is the iron casings used during borehole construction. Cement grout and borehole water are also shielding materials that increase the MDL.

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3.0 MDL CALCULATION METHODOLOGY

Given these variables, the most consistent parameter found to quantify the MDL is the relative error of the net photo peak. In general, 30% relative error of net gamma ray photo peak counts is near the MDL, for all perturbing conditions discussed above. A net peak uncertainty of 30% represents about 5 σ above the background for the algorithms used that will consistently report a photo peak in observed spectra. Also, since the background is determined in a window that is larger than the photo peak region of interest, the MDL level is nearly 1 to 1 for the measured background (discussed below.)

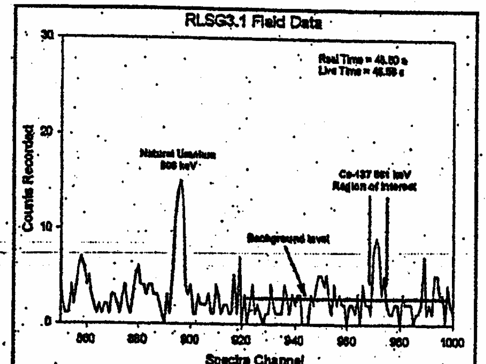

Figure 2. Field collected spectra with Cs-137 identified at MDL.

These conditions are best illustrated by using a specific example. Figure 2 shows a typical spectra with low radionuclide levels in a steel cased well with the 35% HPGe logging system. The plot shows the Cs-137 photo peak at 661 keV, near channel 970. Other than the natural radionuclides (K, U, Th) there is no other (non-natural) radionuclide interference.

The net photo peak counts are 17 with one standard deviation of 5 counts. The total counts in the region of interest (vertical lines) is 40 counts and the background is 23 (computed from the low and high energy windows.) The total background (two sets of 10 channel windows) is 50 counts and relative error of 14%. Therefore, the projected error of the background in the region of interest is 23 $\pm$ 3.22. Furthermore, the net counts at 17 is 5.3 σ of the noise in the region of interest. The relation of net counts in the region of interest of 17 to the background counts in the region of interest of 23 is close to a 1 to 1 relation. The use of wide window (20 channels) for the background calculation greatly increases the precision of the background estimate. The figure of 5 σ varies somewhat as other variables occur (casing thickness, energy resolution, background, etc.), but the most consistent indicator is the relative error of 30% on the net counts in the region of interest for all these conditions.

4.0 CONCLUSIONS

Several variables affecting the MDL of a particular gamma ray (i.e., the source radionuclide) have been described. The magnitude of these effects have been characterized by the use of the precision of the calculation of the net photo peak intensity from the observed data.

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The precision at the MDL of the observed gamma emitting isotope is clearly very low (30% of net peak area), since below this level a statement as to the presence is suspect. Furthermore, the statistical precision is poor at the MDL. It must be noted that depths where a computed concentration reaches MDL bears directly on monitoring comparison (time lapse logs) that may have two different MDL specifications, since the lowest depth of an observed contaminant is a function of the precision of the logging system. Higher quality logging systems (improved MDL) may record the radionuclides at greater depths, while the true formation condition may be unchanged.

ATTACHMENT D. GAMMA RAY ATTENUATION SHIELDING CORRECTIONS ALGORITHMS FOR HPGe LOGGING INSTRUMENTATION OPERATED BY WMNW.

1.0 BACKGROUND

The HPGe logging systems operated by WMNW are run in steel cased boreholes at the Hanford site. The detector efficiency calibrations are performed in uncased borehole models. Therefore, casing thickness corrections must be applied to the observed net photo peak count rates in order to compute accurate radionuclide concentrations. Additionally, the derived correction function was formulated to be consistent with theory and can be used to correct for all attenuating materials with cylindrical borehole geometry (e.g., water inside the borehole with the detector centralized.)

The casing correction factors were empirically determined. Correction algorithms were developed for any low Z (atomic number) element that could be used as a shield, thus expanding the applicability beyond the casing only correction. This report is a description of the data collected to generate the algorithms and the resultant formulation.

2.0 GENERAL THEORY OF GAMMA RADIATION INTERACTION WITH MATTER

There are numerous processes by which gamma rays interact with matter and lose their energy. Fortunately, all these processes do not contribute at an overwhelming extent at gamma-ray energies encountered in the subsurface sediments. The gamma rays emitted in nuclear decay usually have energies ranging from a fraction of a MeV to a few MeV. In this range, the three main processes by which photons lose their energies by interaction with matter are: (a) photoelectric effect (P.E.), (b) Compton effect (C.E.) or Compton scattering, and (c) pair production (P.P.).

These three processes are dominant at different photon energy ranges. The photoelectric effect dominates from 0.01 MeV to 0.5 MeV, Compton scattering from 0.1 MeV to 10 MeV, and pair production starts at 1.02 MeV and increases with increasing gamma energy. All three processes are independent of each other.

The photoelectric effect is more prominent at low energies of the incident photon. The incident photon is absorbed by one of the electrons of the atom. In the process the photon disappears and the electron is ejected with kinetic energy. This photoelectric effect is a complicated function of the Z/A ratio and electron binding energies. The photoelectric effect is dominate at low energies and its cross section falls as the photon energy increases.

The Compton effect is a process by which the incident photon interacts with a free electron and is scattered with a lower energy. The difference before and after the scattering event is taken by the recoiling electron. Because the electrons in an atom are loosely bound and the energies of the incident photons are comparatively high, we may include the scattering of photons by the electrons of the atom as Compton scattering. This process is a simple relation of electron density and gamma ray energy. The logging instrument measurement of radionuclide concentration is based on full energy (uncollided) gamma rays that are recorded in the spectra as gamma ray photo peaks.

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The third most important process by which photons lose their energy is electron-positron pair formation. The threshold energy for this process is twice the rest mass energy of an electron (1.02 MeV). If a photon of energy greater than 1.02 MeV strikes a foil of high Z material, the photon disappears and in its place an electron-positron pair is formed. This process is a complex function of the gamma ray energy and the nucleus with its parameters.

Spectral gamma ray logging in steel (iron) cased boreholes is dominated by the Compton effect (photon energies between 200 and 3000 keV.) The attenuation of gamma rays from the Compton effect is characterized by a point source and a point detector with an iron plate between source and detector. The equation is given by:

$$I = I_0 \cdot e^{-\mu \cdot \rho_e \cdot t}$$

where I is the uncollided (or photo peak) photon intensity after passing through the iron plate of thickness, t, and μ and ρ_e are the absorption coefficient and electron density, respectively. The electron density is obtained from the mass density with a multiplication of the ratio 2*Z/A.

3.0 APPLICATION TO HPGE LOGGING DATA ANALYSIS

The cylindrical geometry of the borehole and logging instrument deviates from the simple theory described above. Likewise, the detector is not a point detector, but has finite dimensions. The radioactive source is distributed uniformly in the formation around the borehole. Given these variations, an empirical solution is sought. The empirical measurements were made with selected sets of casing inserted into a large diameter borehole calibration model in order to measure the attenuation at multiple gamma ray photo peaks. The calibration models at the DOE facility in Grand Junction, Colorado was used for these measurements. The set of models at Grand Junction have a wide range of characteristics, one Mix (K, U, Th) model has a sufficiently large borehole diameter to accommodate the casings.

The following data was collected in 1993 for the HPGe logging system:

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Table 1. Photo Peak Count Rate at Increasing Steel Casing Thickness.

Energy	Net Photo Peak Count Rate (c/s)						
(keV)	0"	0.25"	0.33"	0.38"	0.4"	0.65"	0.98"
186	14.684	5.732	4.096	4.112	3.892	1.631	0.835
239	22.204	10.063	8.001	6.979	7.085	3.355	1.364
242	18.235	8.473	6.602	5.743	5.745	2.639	1.153
295	39.054	19.865	16.227	14.615	14.398	7.474	3.532
352	73.393	39.475	32.152	29.48	28.954	16.058	7.858
463	1.949	1.423	0.929	1.161	1.139	0.667	0.44
583	10.86	6.51	5.692	5.376	5.135	3.422	2.016
610	71.547	43.68	37.498	34.906	34.328	21.778	12.477
727	2.137	1.418	1.257	1.264	1.264	0.761	0.462
768	7.61	4.833	4.331	4.273	4.349	2.766	1.717
911	7.544	5.102	4.507	4.281	4.277	2.848	1.784
934	4.226	2.782	2.561	2.381	2.365	1.651	0.995
968	6.265	4.199	3.804	3.762	3.721	2.475	1.508
1001	1.243	0.759	0.815	0.72	0.836	0.557	0.354
1120	19.205	13.295	11.856	11.2	11.133	7.887	5.092
1155	2.162	1.552	1.43	1.371	1.363	0.943	0.603
1238	7.21	5.18	4.67	4.442	4.326	3.138	2.103
1378	4.596	3.329	2.947	2.773	2.699	1.989	1.359
1408	2.691	1.8	1.656	1.627	2.531	1.171	0.847
1461	4.301	3.209	2.883	2.713	2.713	2.016	1.378
1509	2.517	1.888	1.699	1.614	1.662	1.2	0.833
1729	3.244	2.449	2.164	2.042	2.059	1.52	1.103
1764	17.071	12.773	11.586	11.115	10.97	8.299	5.814
1848	2.212	1.616	1.491	1.442	1.394	1.065	0.769
2204	4.954	3.836	3.494	3.362	3.308	2.599	1.883
2448	1.528	1.163	1.098	1.041	1	0.807	0.588
2615	7.19	5.594	5.197	4.959	4.944	3.934	2.903

The first row contains the total casing thickness, and the first column contains the photo peak energy (keV). The values in the row after each energy is the observed count rate for the column heading casing thickness. And the following table uses the same format, but the cells contain the one standard deviation relative error in %:

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Energy	Standard Deviations in percent						
(keV)	0"	0.25"	0.33"	0.38"	0.4""	0.65"	0.98"
186	1.710792	2.23573	4.503333	5.549797	4.433513	7.003333	2.991062
239	0.38896	1.109959	1.381915	2.763831	1.941638	2.463414	5.239454
242	0.420583	1.125771	1.075174	1.385078	2.02702	1.770875	4.252185
295	0.373149	1.239613	1.299696	0.784245	1.331319	1.103635	3.28801
352	0.186574	0.221359	0.385798	0.739973	0.872789	0.702026	1.157587
463	3.412098	7.106667	4.910000	8.00000	10.55000	7.05000	7.2225
583	0.521776	1.151069	1.88788	1.230126	2.248379	1.884717	1.847521
610	0.189737	0.211873	0.230846	0.366824	0.271956	0.227684	0.386825
727	1.789849	2.770155	3.004164	3.9149	6.327718	4.110961	4.513625
768	1.049876	0.768433	1.663358	1.947963	3.007326	1.66652	2.15063
911	0.439557	1.122609	1.217477	1.299696	1.42935	1.280722	1.68875
934	0.81903	1.856257	2.140862	2.80494	1.192179	1.505244	2.234346
968	1.132095	1.676007	1.432512	1.524218	1.789849	1.593788	1.850408
1001	2.659476	3.614483	5.126052	4.218478	8.336667	5.752183	8.559218
1120	0.357337	0.373149	0.550236	0.629293	0.515451	0.309903	0.69282
1155	1.653871	2.270515	2.102915	2.422305	1.900529	4.174207	3.697928
1238	0.38896	0.727324	0.733648	0.964495	1.378753	1.040389	0.718801
1378	0.616644	1.362942	1.88788	1.511569	1.030903	0.793732	1.160474
1408	1.011929	2.80494	2.453927	9.116667	6.02455	3.283333	7.592156
1461	0.885438	1.324994	1.400889	1.144745	1.549516	1.378753	1.605034
1509	1.641222	2.042831	2.842888	2.264191	2.719559	1.710792	2.217025
1729	0.686214	1.830959	1.122609	2.099752	1.236451	1.729766	1.391414
1764	0.196061	0.338364	0.369986	0.341526	0.449043	0.309903	0.409919
1848	0.917061	1.660196	2.188296	1.824634	1.862582	1.805661	2.179497
2204	0.420583	0.695701	0.664078	0.635618	0.632456	0.951846	0.363731
2448	0.945521	1.555841	1.581139	2.41598	1.245937	0.717837	1.564619
2615	0.27828	0.758947	0.505964	0.752622	0.392122	0.268794	0.32909

A semi-log plot of peak count rate for each photo as a function of the casing thickness confirms the exponential nature of photo peak energy with casing thickness attenuation. Note that the correlation coefficient for each of these energies and an exponential decline with casing thickness was excellent.

The combined factor of each product of μ and ρ. for each energy photo peak were fit for the casing thickness ranges. Note that the casing thickness range covers more than is usual for the boreholes encountered at the Hanford site. A log-log plot of each of these products versus photon energy revealed a straight line. Therefore, a power law least squares fit of these data resulted in the energy functionality of the μ term, since the ρ. component for these data is a constant.

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The rationale for using the ρ notation is discussed later to show its extension to other materials with a different electron density. Thus, a single function can be applied to other shielding conditions (especially boreholes filled with water.) Likewise, cement between two strings of casing can be thickness corrected. However, the KUT component of the cement cannot be removed by this correction. Also, a more precise correction for screened casing is provided.

Figure 1 is a plot of the derived μ values versus the energy for which the absorption coefficient was obtained. Included in the plot is the resulting power law function, (linear plot). The two outlier data points (463 and 1001 keV) have large statistical uncertainty. These two values were not included in the least squares fit for the energy function of the absorption coefficient, but are included in the data plot. The functional form determined is:

$$\mu = a\,CDOTE^{b}$$

where μ is the attenuation coefficient for the iron casing, E is the photon energy in keV, and a and b are the fit results. The values of a and b are:

a-4.584
b- -0.46292

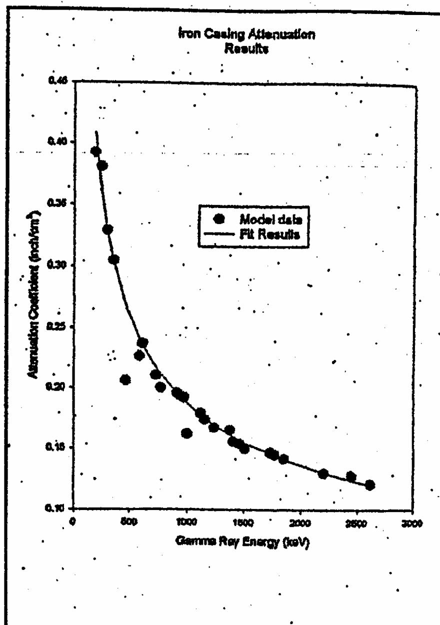

Figure 1. Attenuation coefficient for iron casing data compared to the lead squares fit.

The mass density used for the iron casing was 7.86 g/cm³, and the 2Z/A used is 0.931. Note that casing thickness is characterized in units of inches. This mixture of units is performed in order to achieve ease of use in field operations. Mass density references are most commonly in cgs, but casing thickness measures are generally performed in English units. Incorporating a mixture of units is desirable and is achieved by using consistent multiplicative factors. Likewise, when operations change, the factors can be easily adjusted to accommodate.

Since the correction function includes the attenuation coefficient multiplied by the electron density, this functional form can be directly applied to different materials. To check the application to borehole water correction the predicted correction will be compared to measured data. In particular, a 9 in. diameter model was logged with two borehole conditions, air filled and water filled. The ratio of selected gamma ray photo peaks between these borehole conditions yields the attenuation for water at the annular thickness defined as the difference between the instrument and borehole wall diameters. (The instrument was centralized during data collection.)

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These water data could be analyzed for the attenuation coefficient, as was performed for the iron casing. Alternatively, the iron casing results can be directly applied to the water data as a verification. Since less data exists for the water thickness, this latter verification process is performed. The attenuation ratios for 2.90 inches of annular water for selected energy photo peaks are listed in the following table:

Energy (keV)	Attenuation ratio	1 σ
186	3.94	0.61
239	2.94	0.3
242	3.43	0.38
295	2.88	0.12
352	2.75	0.05
583	2.15	0.12
609	2.23	0.03
911	1.99	0.12
1120	1.87	0.05
1461	1.79	0.11
1764	1.69	0.02
2614	1.53	0.04

The thickness of either the air or water annular region is 2.90 inches. The attenuation values for each of these points is obtained by first, taking the log of the attenuation ratios, second, dividing by thickness, third dividing by the electron density, and last, multiplying by -1 to eliminate the negative. Note the electron density used for water is 1.11 as a result of applying the 2Z/A for the water molecule.

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Figure 2 is a comparison of the measured attenuation coefficient for the water data (circles) and the function developed for the iron casing (line), but using the electron density of water. The excellent agreement lends confidence to the application to other materials, provided the atomic number, Z is less than iron.

Also, included in Figure 2 is the attenuation data for the lead shield that can be used to reduce the RLS instrument sensitivity in high count rate intervals. The deviation of the lead attenuation from both the iron and water attenuation begins at about 1000 keV and increases with decreasing energies. This behavior of the lead attenuation is consistent with the photoelectric effect, which is much larger for lead with its high Z. Therefore, the developed formulation and fitted coefficients appear to be valid for any materials with a Z of iron (26) or less and does not apply for the high density lead shield.

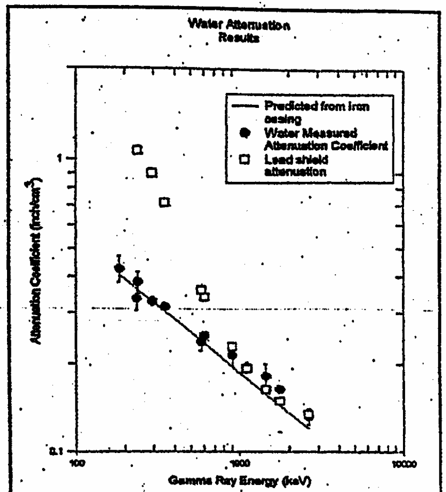

Figure 2. Comparison of theoretical prediction based upon iron casing to the water attenuation in 9 in. borehole.

The remaining deployment of shielding corrections is the addition of a technique to correct for well screen. In this type of casing, there are sections of the casing that are missing (i.e., porosity), and sections typical of iron. Since the attenuation is not linear, a simple linear "effective" casing thickness is not precise. The concept of porosity is applied to the attenuation function using the empirically developed exponential attenuation and coefficients. Thus the total attenuation for any given material is:

$$f = \Phi + (1\Phi)CDOTe^{\mu * \rho_e CDOTt}$$

where Φ is defined to be the percentage of the casing that is missing (in cross sectional area), μ is determined by the previous equation and coefficients, ρ_e is the electron density in g/cm³, and t is the material thickness in inches. The resulting value of *f* is the amount of attenuation of the photo peak net count rate caused by the shielding material. Thus the source intensity is derived by taking the observed net photo peak count rate and dividing by *f*. After this calculation, then the calibration function can be applied to obtain the isotope concentration in the formation behind the casing or other material. (Note that if the casing is solid, (no holes), then simply use a value of zero for the "porosity", Φ.)

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ATTACHMENT E. RLS HPGe SYSTEM DEAD TIME.

1.0 BACKGROUND

All detector electronic systems that process pulses exhibit a phenomena called dead time. The processing of pulses results in a minimum amount of time which must separate two events (pulses) in order that they will be recorded as two separate pulses. In some cases the limiting time may be set by processes in the detector itself, while in other cases the limit may arise in the associated electronics. This minimum time separation is usually called the dead time of the counting system.

Because of the random nature of radioactive decay, there is always some probability that an event will be lost because it occurs within the dead time of the counting system (i.e., a detector captured event occurs too quickly following the preceding event.) These "dead time losses" of non-counted events become severe when high counting rates are encountered. All accurate measuring counting systems include corrections for dead time losses. The RLS HPGe system contains electronic circuitry that accounts for the counting system dead time.

There are two types of dead time character or behavior. They are called "Paralyzable" and "nonparalyzable". A paralyzable system is one in which after processing of an event the system must recover from a signal level to a lower (background) level in order to reset for the next event. The RLS HPGe system is a paralyzable system. It can be shown that the radioactivity can be sufficiently high to create a continuous wave of pulse events that never let the system reset, resulting in a situation in which no detector counts are recorded.

A nonparalyzable system (like the cascading or avalanche discharge of an ion chamber) is one in which the system automatically resets within a specified period of time and the next event triggers the detector pulse again. A nonparalyzable system reaches an asymptotic limit above which the count rate will not increase regardless of increasing radioactivity levels.

Another feature, which is specifically applicable to the RLS HPGe system, is the effect of high count rate on distorting the spectra, creating an apparent loss of photo peak activity, before the system is paralyzed. Since the detector pulse height is proportional to the energy of the detected event, the distortions are caused by pulse pile up with the true pulse height.

2.0 DEAD TIME LIMIT FOR RLS HPGe SYSTEM

Dead time corrections are commonly performed in one of two ways. A post spectra correction can be applied by a mathematical function that accounts for the statistical probability of losses based on a known system dead time and the observed count rate. This mathematical solution requires that the dead time be of fixed duration, regardless of the energy of the detected event. This restriction does not exist for the pulse processing electronics of the RLS HPGe system. The second method is for the counting system electronics to apply the dead time correction at the pulse height analysis. The electronic dead time correction is the method used in the RLS system. With the electronics dead time correction method a "real time" clock runs that records the elapsed time or wall clock time for a given measurement. Also, a "live time" clock is running concurrently, but is temporarily halted

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during each dead time event while each pulse is being processed. This "live time" clock is recording the time that the system is not dead (i.e. waiting to process a detector event.) Thus, the dead time correction is performed by simply dividing the recorded counts by the "live time". The electronics dead time correction method is an integral part of the ORTEC[1] electronics modules.

Standard procedures used in most laboratories to assure accurate analytical results of gamma ray spectrometers is to keep the dead time below 30% or 40% which is accomplished by adjusting the geometry, shielding, and/or sample size to maintained this specification. Even if dead time corrections can be made accurately at higher percentages of dead time, the spectral distortion begins to degrade the resolution. Thus most laboratories use this 30-40% dead time rule of thumb.

Given the cost to extend the operational range (in terms of dead time) of the HPGe system, it was decided to develop smaller detectors with substantially higher effective count rate capabilities. This decision has been vindicated because the smallest detector has successfully measured radiation levels several orders of magnitude greater than can be achieved with even a small shielded 5% HPGe detector.

3.0 CONCLUSION

Given the accuracy range determined for the present RLS HPGe logging system (i.e., less than 30% dead time), a flag is added to the log plots to identify zones where the dead time threshold limit was exceeded in a survey log.

[1]ORTEC is a trademark of EG&G ORTEC.

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VENDOR DATA REVIEW TRANSMITTAL SHEET

June 17, 1999

SUBMITTAL NO.:	PROJECT NO.:	SUBCONTRACT NO.:
S-C95-175003-1064	OU 7-10	WASTE MTG. FEDERAL SERVICES NORTH WEST OPS

SUBMITTAL DESCRIPTION:

PROCEDURES

LINE ITEM(s): "A" MOISTURE LOGGING PROCEDURE
"B" NEUTRON-NEUTRON MOISTURE TOOL CALIBRATION RECORD
~~"C" ACTIVITY, ENCAPSULATION, CHEMISTRY & DOSE RATE INFORMATION FOR NEUTRON-NEUTRON TOOL SOURCE"~~
"D"
"E"
"F"

REVIEW AND COMMENT REQUEST FORM

DOE -	☒ ES&H - JIMMY WILBURN	☐ OTHER - SCOTT VERSLUIS
☒ CAM - MARTY DOORNBOS	☒ DICK ROBLEE	☐ OTHER - NICK JOSTEN
☒ QA-	☐ LITCO - RICK HORNE	☐ OTHER - TOM SHERWOOD

RECORD COMMENTS ON ATTACHED REVIEW RECORD FORM.
RECORD RECOMMENDED DISPOSITION BELOW.

IF COMMENTS ARE NOT RECEIVED OR NO CONTACT MADE WITH THE RESPONSIBLE ENGINEER BY THE REQUIRED RETURN DATE, IT WILL BE EVIDENCE THAT THE REVIEWER CONCURS WITH DOCUMENT IN REVIEW. THE ENTIRE PACKAGE MUST BE RETURNED TO THE RESPONSIBLE ENGINEER, EVEN IF NO COMMENTS ARE MADE.

RETURN COMMENTS AND SUBMITTAL PACKAGE TO THE RESPONSIBLE ENGINEER.

RESPONSIBLE ENGINEER:	AT:	BY:
MARTY DOORNBOS	MS/3954 TSB	JUNE 21, 1999

REVIEW COMMENTS AND DISPOSITION

LINE NUMBER	RECOMMENDED DISPOSITION	LINE NUMBER	RECOMMENDED DISPOSITION
A			
B			
C			

REVIEWER: DATE:

APPROVAL AUTHORITY DISPOSITION

SUBMITTAL DOCUMENTS HAVE BEEN REVIEWED, COMMENTS FROM OTHER REVIEWERS INCORPORATED OR RESOLVED, AND FINAL COMMENTS AND DISPOSITION PROVIDED.

DISPOSITION: ☐ A ☐ B ☐ C ☐ D | COMMENTS: YES ☐ NO ☐ ATTACHED: ☐

RESPONSIBLE ENGINEER: DATE:

X-30244

ERP-132-92 (8/92)

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DOCUMENT REVIEW RECORD

☐ Project Document
☐ Design document
☒ Vendor Data

Project: Document Number/Title:

Submittal No: Reviewer: Review Date: Page: 1 of

ITEM NUMBER	SECTION NUMBER	PAGE NUMBER	CODE	COMMENT	COMMENT RESOLUTION
					12-0160125 LMIT

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Comment Resolutions Accepted By Reviewer: Date:

Codes: M - Significant comment requires resolution acceptance from Reviewer. S - A suggestion to improve the document: resolution response required. E - Editorial comment that, if incorporated, would improve the document.

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TITLE:

Vadose Neutron Moisture Logging Procedure

Approved

J. J. Dorian, Program Manager
Environmental Monitoring & Investigations

1.0 PURPOSE

Information Only

This logging procedure provides guidelines and minimum requirements for neutron moisture borehole logging. This logging may be related to collecting data for radioactive waste detection and assessments, radioactive waste storage tank monitoring, environmental investigations, and site characterizations.

This procedure specifies personnel qualifications, personnel responsibilities, and general and specific methods that will be used to obtain geophysical log data, by Waste Management Federal Services, Inc., Northwest Operations.

2.0 LIST OF TERMS

ac	alternating current
cm	centimeter
DOT	U.S. Department of Transportation
ft	foot
ft/min	feet per minute
HPT	health physics technician
Hz	hertz
in.	inch
kg	kilogram
kPa	kilopascal
lb	pound
m	meter
m/min	meters per minute
psi	pounds per square inch
PTO	POWER-TAKE-OFF (switch)
rpm	revolutions per minute
RRSR	Routine Radioactive Shipping Record
RWP	Radiation Work Permit
V	volt
WMNW	Waste Management Federal Services, Inc., Northwest Operations

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3.0 RESPONSIBILITIES

3.1 PROJECT MANAGER

- Designates the storage location for each logbook (maintained in appropriate logging truck).
- Ensures that the logbook is protected against damage, loss, and unauthorized changes.
- Determines priorities and schedules.
- Approves reports and other technical products before they are released to the customer.

3.2 PROJECT TECHNICAL LEAD

- Coordinates all data acquisition, data interpretation, and reporting for a particular project.
- Determines the priorities for data acquisition. Reviews the priorities with the customer, logging engineers, and other field personnel to ensure that they establish and achieve realistic goals.
- Ensures personnel have required training, equipment is certified, and Radiation Work Permits (RWP) are in place.
- Along with the project manager, monitors the effectiveness of this logging procedure and, when necessary, revises and approves revisions. Temporary revisions may be entered with pen and ink for a stated time or until the procedure is revised.
- Approves work products.

3.3 LOGGING ENGINEER OR LOGGING GEOPHYSICIST

- Ensures that the project logging equipment is calibrated, reviews schedules for logging activities, and works with the project technical lead to ensure that Site- or project-specific methods, such as counting times and data acquisition intervals, are understood and implemented. Ensures that routine maintenance of the logging unit is performed.
- Attends prejob briefings to advise support staff of the location of the borehole(s) to be logged, the work plan for the day, the RWP, and any other safety precautions requiring special consideration.
- Verifies the identity and features (depth, zero-depth reference, and casing configuration) of each borehole to be logged.

- Performs data acquisition.

- Performs or supervises the presurvey field verification check, the borehole survey, and the postsurvey field verification check.

- Observes the radiation surveys of field personnel and logging equipment and arranges for the decontamination of the equipment if radioactive contamination is detected.

- Documents (or supervises the documentation of) field logging operations by completing Borehole Survey Data Sheets (see example in Attachment) and maintaining a Borehole Survey Data Journal consisting of the collection of Borehole Survey Data Sheets.

- Delivers log records to the customer.

3.4 LOGGING TECHNICIAN

- Verifies and records the identity and features (depth, zero-depth reference, and casing configuration) of each borehole to be logged. Records any information that may be pertinent to data processing and interpretation of results; e.g., equipment malfunction, drilling problems.

- Performs the presurvey field verification check, the borehole survey, and the postsurvey field verification check.

- Performs data acquisition.

- Arranges for the decontamination of the equipment if radioactive contamination is detected.

- Documents field logging operations by completing Borehole Survey Data Sheets (see Attachment) and maintaining a Borehole Survey Data Journal consisting of the collection of Borehole Survey Data Sheets.

4.0 REQUIREMENTS

4.1 PERSONNEL QUALIFICATIONS

4.1.1 Logging Engineer or Logging Geophysicist

The logging engineer or logging geophysicist must meet the following requirements:

- Hold a bachelors' degree with a major in geophysics, engineering, or a physical science with courses selected from geology, hydrology, physics, chemistry, applied mathematics, and engineering

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- Have two or more years of applicable professional experience or hold an advanced degree in an appropriate technical discipline

- Have completed one undergraduate course in applied nuclear physics or the equivalent of nuclear logging education and professional experience

- Have passed all required training, including Radiation Worker Safety training, and be willing to use radioactive sources

- Hold a Class B Commercial Driver's License

- Be trained in proper operation of logging crane

- Possess knowledge of the following:

  - The particular logging methods used at the Hanford Site, including calibration methods and borehole environmental correction methods

  - Use of the specific instrumentation used for moisture (porosity) logging, including a Windows[1]-based personal computer

  - General features of nuclear logging equipment, including radiation detector physics, radiation detector types, detector energy resolution, electronic circuitry, and recording methods

  - Basic log interpretation principles

  - A degree of knowledge of the logging systems utilized that allows troubleshooting of problems in the field.

The project manager may approve waivers or substitutions to particular items in the above list. A record of this action, accompanied by the justification and the name of the individual for whom the waiver or substitution applies, must be properly documented in the project records.

4.1.2 Logging Technician

The logging technician must meet the following requirements:

- Hold a two-year degree, or higher, in a technical field

- Possess basic knowledge in gamma ray detection physics

[1]Windows is a trademark of Microsoft Corporation.

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- Possess basic skills in computer operations
- Have the ability to understand basic functions of logging truck components, including depth encoder, boom control, drawworks, nitrogen monitor, and truck engine monitors
- Have passed all required training, including Radiation Worker Safety training, and be willing to use radioactive sources
- Hold a Class B Commercial Driver's License
- Have the strength and dexterity to handle field equipment (logging cable, shields, collimators, and logging tools up to 29.5 kg [65 lb])
- Possess basic skills with hand tools used in logging operations, including pliers, wrenches, socket wrenches, screwdrivers, and nut drivers
- Have the ability to operate hydraulic boom control and drawworks
- Be trained in proper use of logging crane.

The project manager may approve waivers or substitutions to particular items in the above list. A record of this action, accompanied by the justification and the name of the individual for whom the waiver or substitution applies, must be properly documented in the project records.

4.2 HEALTH AND SAFETY REQUIREMENTS

All borehole geophysical logging operations, including subcontracted work, will comply with applicable health and safety plans, procedures, and regulations; RWPs; contractor safety plans; and applicable project-provided safety plans (e.g., Health and Safety Plans, [HASPs] or Hazardous Waste Operating Permits [HWOPs]).

The Activity Hazard Analysis for Sitewide geophysical logging addresses equipment setup, sonde movements and pinch points, logging system electronics, use of hand tools and test equipment, off-road vehicle use, responses to environmental conditions, and use of safety equipment.

4.3 QUALITY ASSURANCE REQUIREMENTS

All borehole geophysical logging operations, including subcontracted work, will comply with applicable quality assurance plans, procedures, and regulations.

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4.4 RECORDS MANAGEMENT REQUIREMENTS

All borehole geophysical logging operations, including subcontracted work, will comply with applicable records management plans, procedures, and customer requirements.

5.0 PROCEDURE

5.1 LOGGING OPERATIONS

5.1.1 Preparations

The driver of the logging truck will perform a vehicle inspection at least once per day before truck movement. If the truck is to be moved onto a public highway, this inspection will comply with all U.S. Department of Transportation (DOT) requirements and will be documented as per DOT regulations (49 CFR, "Transportation"). Personnel driving the logging trucks on public roads are required to have a valid Class B Commercial Drivers License.

A "blue card" Routine Radioactive Shipping Record (RRSR) must be used to ship the neutron source on the Hanford Site. This requires a health physics technician (HPT) survey and signature before moving the source from the storage location to the well site. HPT survey and signature are also required when moving the source back to the storage site or to another location. The operator must conform to all requirements of the RRSR and make sure it is valid.

Truck movement will be conducted on established roads unless access to a borehole requires off-road driving.

Each employee will comply with access requirements for entrance to a regulated site. Each employee will become familiar with current site conditions as reflected in the RWP, work package, or any other requirements established at the logging site. Access to the logging site may occur only with the approval of customer personnel.

The logging engineer or logging technician will conduct a prejob briefing to inform the staff of the location of the borehole(s) to be logged; the work plan for the day; RWP requirements; and any other topics needing introduction, clarification, or reinforcement.

After arriving at the borehole, the logging engineer/technician will verify the borehole identity and the pertinent features, including borehole depth, zero-depth reference, casing configuration, and contaminant-bearing depth intervals (if known). Any information that may affect data processing and/or interpretation of results should be recorded.

Before starting the logging operation, the logging engineer/technician will ensure that the instruments and mechanical systems are operational and the calibration is current per WHC-SD-EN-TI-306, *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration* (Meisner et al.1996).

The logging engineer/technician will verify the readiness of the logging system and will confirm the system calibration.

The logging engineer/technician will have customer support personnel (Operations or HPTs) check the inner surface of the borehole casing for smearable contamination. If the borehole casing has no smearable contamination, the sonde can be placed in the borehole without a protective covering. If smearable contamination is detected inside the casing and its activity is within the values specified on the RWP, the sonde will be inserted in a plastic sleeve before logging. This protective sleeving should be of adequate thickness to protect against rips and tears as the sonde is lowered and then pulled back up the borehole. After logging a contaminated borehole, the protective sleeving will be carefully removed by operations personnel and packaged as radioactive waste. Health physics personnel will survey the sonde for contamination and, if needed, decontaminate it before logging is allowed to continue in the next borehole.

If smearable contamination is in excess of the values specified on the RWP, the logging engineer/technician will stop work on that particular borehole and notify the project technical lead of the unexpected existing conditions. The project technical lead will investigate and determine an appropriate course of action.

5.1.2 Logging

The logging engineer/technician will record all pertinent information on a Borehole Survey Data Sheet as follows:

1. Indelible black ink is preferred for handwritten entries; however, indelible blue is acceptable. Nonphoto blue (i.e., a color that will not be clearly duplicated by a photocopy machine) is not acceptable.
2. If a particular data field is *not applicable*, enter "N/A" in the space for that field.
3. Line out incorrect information with a single line and write the correct entry next to the incorrect one. Initial and date the correction. Do not use correction fluid, erasers, or highlighter pens to make corrections.

5.1.2.1 Logging Truck Start-up Procedure.

1. After the logging unit is in position to log the borehole, apply the parking brake and place one set of wheel chocks.
2. Connect the hydraulic generator power cable to the main plug at the alternating current (ac) input panel and turn ON the main circuit breaker. This step is only necessary if the logging unit has been connected to external power and will be switched to generator power.
3. Go to the front driver cabin and put the gearshift lever in neutral, turn OFF the POWER-TAKE-OFF (PTO) switch (right-hand position), and put the transfer case switch to neutral (middle position).

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4. Turn the engine ON from the front driver cabin and wait until the air-tank gauge indicates more than 620.5 kPa (90 psi) and the low air pressure warning alarm turns OFF (the transfer case and PTO witches operate by air pressure and will not activate unless there is adequate air pressure).

5. While depressing the clutch, put the truck in sixth gear and turn ON the PTO switch (left-hand position). The red PTO light illuminates when the switch is ON.

6. SLOWLY release the clutch to engage the PTO. The red LED light illuminates on the CONSOLE when the PTO is engaged.

5.1.2.2 Logging Truck Power-Up/Power-Down Sequence for the Instrument System.

1. Make sure all circuit breakers and individual power switches are in the OFF position at the beginning of this sequence.

2. Turn ON SENSOR and CONSOLE circuit breakers on the right-hand (direct current) side of the breaker panel. The CONSOLE instrument gauges and the red direct-current light on the SENSOR PANEL energize. Make sure the winch is not turning at this point by pushing down the EMERGENCY STOP button on the console. When the EMERGENCY STOP button is engaged, the red brake light above it illuminates.

3. Bring the engine revolutions per minute (rpm) up to approximately 1,100 rpm by turning the THROTTLE on the CONSOLE counterclockwise. Check the generator voltmeter and frequency-meter at the power distribution panel. Adjust the THROTTLE until the meters indicate 120 V ac and 60 Hz.

4. Turn ON COMPUTER, WALL 1, ac, and WALL 2 circuit breakers on the left-hand (ac) side of the breaker panel.

5. Turn ON the UNINTERRUPTIBLE POWER SUPPLY (top button for on, bottom button for off), hold for 1 second; in sequence, turn ON the NIM BIN POWER SUPPLY, OPTICAL DISK DRIVE, COMPUTER MONITOR, and, lastly, the COMPUTER CENTRAL PROCESSING UNIT. The electronic system should warm up approximately 30 minutes before data collection.

   NOTE: The computer may not boot properly unless the NIM BIN is turned ON before the COMPUTER CENTRAL PROCESSING UNIT.

When shutting the instrument system down, the sequence should be reversed.

5.1.2.3 NIM BIN Power Supply.

1. Before connecting or disconnecting the cable head to the sonde, switch OFF the NIM BIN power supply. Connecting or disconnecting the cable head and the sonde with the NIM BIN power ON could cause an electronic failure in the tool.

2. Turn the NIM BIN power ON after the sonde has been connected. By following this sequence, the computer will not have restarted.

5.1.2.4 Logging Truck Crane Control. Only authorized personnel may maneuver and operate the crane.

1. Make sure there are no overhead power lines within 3.05 m (10 ft) or other nearby overhead equipment that could contact or come near the crane.

2. Set the outrigger pads and deploy the outriggers to stabilize the crane.

3. Do not attempt to completely unload the vehicle suspension.

4. Adjust the outriggers until the sight-level gauge at the base of the crane is level.

5. Close the valves on the legs when in place.

The crane and winch may be operated either from the REMOTE PENDANT or from the CONSOLE (hoist) and HYDRAULIC CONTROLS at the base of the crane.

5.1.2.5 Remote Pendant Crane Operation.

1. Make sure there are no overhead power lines within 3.05 m (10 ft) or other nearby overhead equipment that could contact or come near the crane.

2. Set the HOIST switch on the CONSOLE to MANUAL and check that the red REMOTE LED is lit.

3. Release the EMERGENCY STOP button by twisting clockwise.

4. To select the REMOTE PENDANT for crane operation, go to the back of the truck and switch the HYDRAULIC CONTROL lever at the base of the crane to the left-hand position.

5.1.2.6 Manual Control Crane Operation.

1. Make sure there are no overhead power lines within 3.05 m (10 ft) or other nearby overhead equipment that could contact or come near the crane.

2. Set the HOIST switch on the CONSOLE to MANUAL and check that the red REMOTE LED is lit. Leave the EMERGENCY STOP button ON, locking the winch.

3. To select MANUAL CONTROL crane operation, go to the back of the truck and switch the HYDRAULIC CONTROL lever at the base of the crane to the right-hand position.

4. Bring the crane out of the resting position, then connect the sheave-measuring wheel. The measuring wheel should be positioned so the encoder box (cable connections) is facing the driver side of the vehicle.

5. Connect the encoder cable to the encoder box. Connecting this cable to the box may create a weight overload signal to the sensor box. If this condition happens, the red EMERGENCY STOP LED on the CONSOLE turns ON, and control of the winch is locked out. To reset this lockout condition, cycle the EMERGENCY STOP button on the CONSOLE ON and OFF twice.

6. Roll out the logging cable using the remote pendant or the hoist control handle on the console.

7. Put the cable through the measuring wheel (the potentiometer controls the roll-out speed and is located on the bottom of the auto-fill junction box near the tool rack).

8. Position the cable head above the well using the crane.

9. Hook the two support legs on the end of the crane to stabilize it when logging.

10. Using the crane, lightly apply hydraulic pressure downward on the support legs, locking them in place.

5.1.2.7 Logging Tool.

1. Remove the logging tool from the truck's tool rack. Make sure the NIM BIN power is OFF.

2. Connect the logging tool adapter to the cable head carefully. Be very careful not to nick or cut the O-ring on the probe. If the O-ring is damaged or worn, replace it with a new one and lightly grease it. Simultaneously position the alignment pin on the probe with the notch on the cable head body and join the 22 pin step-up/step-down connector together.

3. Tighten the cable head and locking ring. The tool is ready to be controlled from the instrument cabin.

4. Remove neutron tool from source storage compartment with source shield/ calibrator attached.

5. Carefully connect neutron tool to logging tool adapter.

6. Switch the HOIST SELECTION switch on the console to COMPUTER and check that the red COMPUTER LED is lit. The winch is now under computer control.

7. Turn the NIM BIN power ON. Allow instrument to stabilize for approximately 20 minutes before data collection.

5.1.2.8 Computer Automated Spectral Acquisition System II (CASASII) Logging Setup.

1. The CASASII program may be started from the DOS prompt by entering: LOG <CR>. The program then displays the 12 CASASII Main Menu commands. The 12 main menu commands are started using the keyboard function keys F1 through F12. Pressing <ESC> returns the user to the main menu. See the CASASII User Manual (Greenspan 1994) for additional information.

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2. Execute FILE/DIRECTORY COMMANDS (F6) from the main menu, and select SET DEFAULT DATA DIRECTORY (F1 on the directory screen) or MAKE DATA DIRECTORY (F3 on the directory screen). SET DEFAULT DIRECTORY allows the user to set the default data directory to any directory that already exists. MAKE DATA DIRECTORY allows the user to create a new data directory. All data directories have the ".DIR" extensions. Setting this directory at startup is important.

3. Enter the DIRECTORY name according to the labeling system developed for the borehole. Execute the LOAD INITIALIZATION DEFAULTS (F8) command and respond by entering "MOIST".ini. This will load the correct 921 module settings.

   NOTE: The Ortec multichannel analyzer program called "M2SETUP" must have been executed to 512 channels and the multichannel analyzer program must have been run before this will work.

   Execute LOG INITIALIZATION (F1) from the main menu and enter the well identification, well location, experimenter, filename header, and other logging information.

4. Each spectrum will be named with an eight-character label. The filename header is the first through fifth characters and must be entered by the logging engineer or the logging technician. The logging software will determine the sixth through eighth characters and attach the ".CHN" extension.

5.1.2.9 Detector Presurvey Field Verification.

1. Execute DETECTOR CALIBRATION (F2) from the main menu screen.

2. Select PRESURVEY (F7 on the calibration screen) and set up to acquire a spectrum for 100 seconds real-time counting time. Press F5 to begin the collection.

3. The neutron peak shown in the displayed spectrum should be located in channel 380 of the 512-channel spectrum.

4. Press F12 again to toggle the acquisition controls.

5. Select Cursor 1b, using F11, and move it onto the centroid of the neutron peak using the cursor control keys. Note the channel indicated on the screen.

6. Adjust the fine gain on the 672 amp, as necessary, and press F10 to restart the acquisition.

7. Repeat this process until the neutron peak is in channel 380. Typically the signal gain will stabilize near the end of the 20-minute warm-up period, so do not make these fine adjustments until the end of this period. When the peak has stopped drifting, let the system count for the full 100 seconds.

8. The spectrum will be displayed on the computer monitor. The logging engineer will verify that a full spectrum has been acquired and that the neutron spectrum has the expected shape.

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9. After the PRESURVEY collection is complete, write the current spectrum to the default directory. All precalibration files have the ".CAB " extension.

10. If the logging engineer/technician's professional judgment indicates that the system is ready to log the borehole, then the logging engineer (or the logging technician, acting under the logging engineer's instructions) will fill out the appropriate spaces on the Borehole Survey Data Sheet and do the following:

    a. Position centralizer on the sonde when logging 15.2-cm (6.0-in.), 20.3-cm (8.0-in.), and 25.4-cm (10.0-in.) boreholes.

    b. Install logging accessories such as a shield or plastic wrap, if needed.

5.1.2.10 Setting the Initial Depth.

1. Remove the source shield/calibrator and position the probe in the borehole so that the top of the cable head is level with the zero-depth reference. The zero-depth reference is usually the top of the casing, but the ground surface or other reference is acceptable.

2. Note the zero-depth reference on the Borehole Survey Data Sheet. If a reference other than the top of the casing is used, note the measurement of the distance to the top of the casing on the Borehole Survey Data Sheet.

3. Reset the depth counter on the console.

4. Execute DEPTH CONTROL (F3) on the main menu. Several commands are available to control the probe's depth and start and stop positions.

5. Use F2 to enter the well depth and tool position, which is 4.19 m (4.88 ft) .

6. Use the computer to move the probe to the bottom of the well, entering a stop depth that is several feet above the reported bottom. The operator sets the speed with which the tool will descend. The hoist is designed not to exceed a speed of 9.14 m/min (30 ft/min).

7. Watch the strain indicator while running into the borehole. When the hoist stops, use the joystick to move the probe to the bottom of the well.

8. When the load falls off, stop the hoist, then raise the probe until the load increases.

9. Note the total depth of the well on the Borehole Survey Data Sheet.

   NOTE 1: Pressing <ESC> anytime will stop the hoist, as will pressing the STOP button.

   NOTE 2: Use the computer to set the depth to an even 15.2-cm (0.5-ft) increment before acquiring data to standardize data processing.

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5.1.2.11 Acquiring Spectra.

1. Execute ACQUIRE SPECTRA (F4) on the main menu. This function may only be invoked if LOG INITIALIZATION (F1), DETECTOR CALIBRATION (F2), and DEPTH CONTROL (F3) have been executed previously and are noted on the CASASII main menu screen by checkmarks to the right of their titles.

2. Select logging mode (F1), CONTINUOUS.

3. Set the depth increment at 7.62 cm (0.25 ft).

4. Start the (software controlled) logging run (F5).

5.1.2.12 Logging Reruns. A logging rerun is performed as a quality control check of the precision of the detector and associated electronics. A minimum rerun interval of at least 10 ft will be performed in each borehole under the same conditions of the primary moisture survey (e.g., logging speed).

Depth intervals that should be considered for reruns are intervals of moderate gamma-ray intensity, intervals that include overlaps of consecutive log runs, or intervals within which the gamma-ray intensity increases or decreases. The logging engineer/technician will select the interval and note the reason for the selection on the Borehole Survey Data Sheet.

Treat the rerun interval as a separate log run and note it on the Borehole Survey Data Sheet as a logging rerun. Collect the rerun using the same data acquisition parameter utilized for the logging operation.

5.1.2.13 Zero-Depth Reference Check.

1. Following completion of the logging run, the sonde will be returned to the position where the top of the cable head is level with the zero-depth reference point.

2. If the depth readout does not indicate 1.49 m (4.88 ft), record the error on the Borehole Survey Data Sheet. Use a positive symbol ("+") to designate a reference above the zero and a negative symbol ("-") to designate a reference below the zero. Make a notation on the Borehole Survey Data Sheet even if there was no depth-return error to indicate the reference was checked.

3. Remove the instrument from the borehole using the hoist and immediately replace the source shield/calibrator on the instrument.

5.1.2.14 Detector Postcalibration. At the end of each day, the logging engineer/technician will obtain a postsurvey verification.

1. Execute DETECTOR CALIBRATION (F2) on the main menu and select POSTCAL by toggling F7 on the calibration screen.

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2. Acquire a postsurvey neutron spectrum for 100 seconds real-time counting time. All postcalibration files have the ".CAA" extensions.

3. Press SAVE (F6) on the calibration screen to write the current spectra to the default directory.

5.1.2.15 Equipment Rig Down

1. Copy the data files from the hard drive to the optical disk following the directory hierarchy specified in the procedures manual (Greenspan 1994).

2. Turn OFF the NIM BIN power before separating the sonde for storage. Place the sonde in the source storage compartment of the logging truck. Place the logging tool adapter into the tool rack.

3. Remove the logging cable from the measuring sheave wheel; then remove the sheave wheel from the boom.

4. Retract the boom and outriggers and lock in the traveling position.

5. Complete any remaining items on the Borehole Survey Data Sheet.

6. Complete and sign the logbook entries for the day.

7. Secure loose items, stow portable stairs, and secure doors. Place unsecured items cabinets or secure by approved means before moving the logging truck.

8. Before exiting the control cabin, turn OFF the electrical system and disengage the PTO throttle. Lock the door after exiting.

9. Walk around the truck before moving it.

5.1.3 Decontamination

The HPTs will survey the logging cable and sonde as they emerge from the borehole and after the logging is finished. If radioactive contamination is detected, customer personnel will decontaminate the affected equipment according to customer procedures.

The logging engineer/technician will take all possible measures to prevent or limit contamination of the equipment. If radioactive contamination is detected on the down-hole equipment, it will be decontaminated before use in another borehole. All instruments and equipment must be surveyed for radiologic contamination before being removed from a surface contamination zone. The Hanford Site contractor will provide an HPT for radiologic contamination control. Any movement of equipment or personnel out of the zone will be coordinated with the HPT.

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5.1.4 Records

The vadose zone moisture logging records consist of the following:

- Logbook
- Borehole Log Data Sheets
- Neutron data files.

Logbooks describe the process for controlling operating logbooks and other records to ensure complete and accurate operational histories of truck activities. This procedure applies to all personnel who use and maintain logs and records.

5.1.4.1 General Requirements. Logbooks used for logging activities are numbered on the outside front cover, have horizontally ruled pages, and are sequentially numbered on each page.

5.1.4.2 Logbook Requirements. The truck logbook contains the following:

- Major equipment status (outages) changes
- Major system and equipment testing
- Data file sequence number
- Well data, depth, and water level
- Logging parameters, speed, and time or depth interval.

Record events as completely as possible, and communicate information as clearly as possible to maximize understanding by logbook readers.

5.1.4.3 Logbook Entry Requirements

1. Make entries in blue or black indelible ink.

2. Correct entries, if necessary, to ensure readability and accuracy. Do not erase the original entry or use correction fluid, tape, or other method of correction that will obliterate, obscure, or remove that entry. Make corrections by drawing a single line through the entry, inserting the correct information as closely as possible to the original entry, and initialing and dating the correction.

5.1.4.4 Vadose Zone Neutron Moisture. Logging records consist of the completed Borehole Survey Data Sheets and the spectral data files.

The logging engineer will complete the Borehole Survey Data Sheets, when practical, after the logging run is finished.

5.1.4.5 Spectrum Data Files. These are recorded by software and must be zipped, stored, and backed up at the end of each logging run on a second drive, optical disk, or floppy disk. This data file record is returned to the office for archiving.

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6.0 REFERENCES

49 CFR, "Transportation," *Code of Federal Regulations*, as amended.

Greenspan, 1994, *Computer Automated Spectral Acquisition System II (CASASII) User Manual*, Greenspan, Inc., Houston, Texas.

Meisner, J. E., R. K. Price, and R. R. Randall, 1996, *Radionuclide Logging System In Situ Vadose Zone Moisture Calibration*, WHC-SD-EN-TI-306, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

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7.0 ATTACHMENT: BOREHOLE SURVEY DATA SHEET

BOREHOLE SURVEY DATA SHEET

Project: | Well Name: | Well ID:

Date: | Location:

Notes: ______

BOREHOLE LOGGING INFORMATION

Logger: ______ Logging Unit Configuration: ______

Depth Datum Reference: ______ Instrument Calibration Configuration: ______

Total Well Depth: ______ ft Source: ______ Water Level: ______ ft Source: ______

Source for Casing Parameters: ______

Casing Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

Diameter: ______ in. Wall Thickness: ______ in. Type of metal: ______ Total Depth: ______ ft Stickup: ______ ft

File Name Prefix ______ Field Disk/Part. ______ Return Error: ______ in. (High/Low) at ______ ft Field Verifier ID: ______

Pre Log Verification: Gross ______ c/s Background ______ c/s Th 583 keV photo peak FWHM ______

Post Log Verification: Gross ______ c/s Background ______ c/s Th 583 keV photo peak FWHM ______

Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft
Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft
Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft
Log Interval: Fix Speed ______ fpm Move-Stop-Acquire ______ s (LT/RT)
Depth Range: Start ______ ft Stop ______ ft Incr ______ ft

LOGGING OPERATIONS WERE PERFORMED AND EQUIPMENT CLEANED AS PER PROCEDURES, 17.0 GEOPHYSICAL LOGGING WASTE MANAGEMENT - NORTHWEST

Prepared by (print) ______

Signature:

Date: ______

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Three Rivers Scientific
3659 Grant Ct, West Richland, WA 99353 (509) 967-2381

COPY May 17, 1999

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Steve Kos
Waste Management NW

Dear Steve Kos,

Enclosed are the following:
1. Calibration Certificate for RLSM3.1
2. Mathcad analysis file & print out
3. Spreadsheet statistical analysis file & print out
4. Diskette containing electronic files (MST3-1_5-13-99.zip)

Observations and Recommendations

The statistical response of the instrument during all model data collection is within expected limits for the count rates encountered. The instrument did not introduce additional sources of random errors. Likewise, the power law fit was observed to agree within the statistical precision.

The difference in the reading in the verifier at the start of the day from the reading at the end of the day is near 2 σ. Changes in physical location can account for the small difference. Therefore, the verification results indicate the instrument was stable during the calibration.

There is no observable difference in the calibration function over last year's results. However, the results appear to have slightly different coefficients, but the resulting function difference is much less than 1%.

The data collection experienced a computer malfunction in the recording of the electronic raw spectral files. Real time displays of the observed and dead time corrected count rates were manually entered into the log book and these data were used to perform the calibration.

There is one draw back to this instrument; it has no gamma ray detection for a void space indication. The trade off with this RLSM3.1 instrument over the one containing both a neutron and gamma detector is that the RLSM3.1 has a more efficient detector, which affects logging speed. The particular instrument containing the gamma and neutron detector should be upgraded to a more efficient neutron detector, thus yielding both improved statistical precision and the second information signal.

Please feel free to contact the undersigned at 967-2381 for any information desired.

Russel Randall

Russel Randall

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Certificate of Calibration
RLSM3.1
May 13, 1999

Data were taken at the Pasco models on May 13, 1999. RLSM3.1 is the designated moisture tool M3 in the version .1, thus the M3.1. There is no change in the version, since no instrument changes have occurred during the time from previous calibration. This calibration is the required yearly quality performance.

Six models were used for moisture calibration, 3 for 6"casing and 3 for 8" casing. Repeated spectra were recorded for each model in order to perform statistical analysis. The observed statistical variation agreed with the theoretically predicted variation, refer to the file Stats.XLS for this analysis.

The coefficient generation is determined by the algorithm described in the document WHC-SD-EN-TI-306, Rev. 0. The regression function used is a power law form and defined by:

$$V = a \cdot CR^{\alpha}$$

Where V is the formation moisture content in volume fraction water in vf units. One vf unit is 1% by volume water. The coefficients a and α are fit coefficients, and CR is the deadtime corrected observed total count rate, (c/s).

6" casing	8" casing
a = .0000490	**a = .00001597**
α = 2.206	**α = 2.537**

Digital files condensed as MST3-1_5-13-99.zip. This compressed file contains:

- Calibration raw data
- MathCad data analysis files
- Spreadsheet data formatting
- Cover letter noting results and/or recommendations
- Log data collection reporting files

Signature:

Date:

May 17, 1999

Company:

Three Rivers Scientific

1999 RLSM3.1 Calibration Certificate

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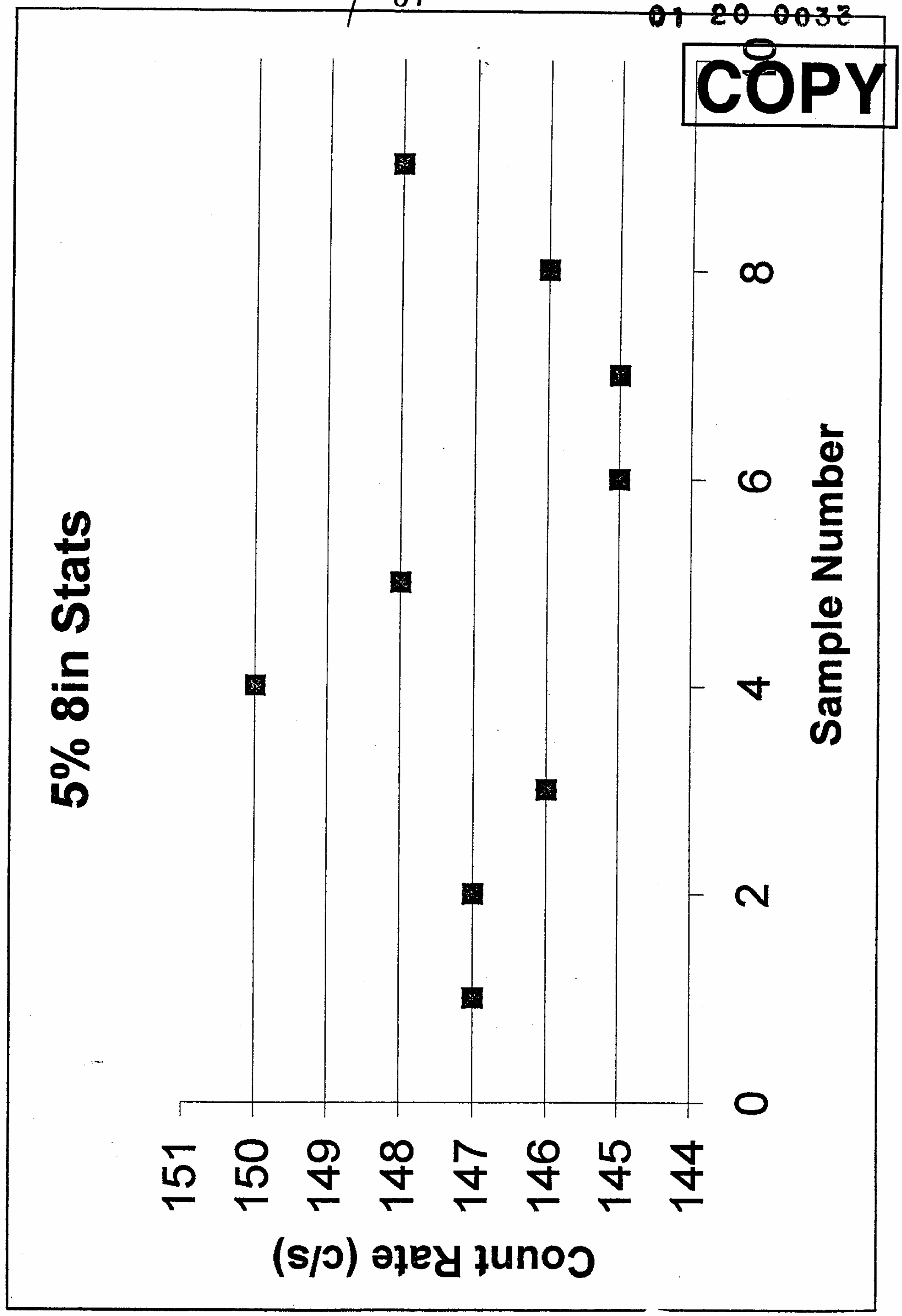

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COUNT RATES RECORDED IN LAB BOOK DURING MOISTURE CALIBRATION 5/13/99
(spectral files were lost due to computer malfunction)
counts per live second:

5%,6in.	5%,8in.	
7@30s	9@30s	
188	147	
189	147	
186	146	
186	150	
189	148	
189	145	
184	145	
2@100s	146	
186	148	Theory sig
185	146.8889	0.015064
	1.615893	
	0.011001	obs sig
	2@100s	Weighted
186.4146	147	146.5106
Weighted	145	0.013333

12%,6in.	12%, 8in.
5@40s	7@30s
280	204
276	208
272	206
278	205
277	209
2@100s	203
273	206
275	2@100s
	206
	207
275.3	206.125
Weighted	Weighted ave

20%,6in.	20%,8in.
3@100s	1@30s
351	250 no count round off
346	2@100s
347	250
2@100s	253
350	
345	
1@30s	
356 no count round off	
Weighted	Weighted ave
347.8	251.5

all above data taken at model midplane (3 ft depth)

verifier before(c/s)	verifier after (1)	verifier after (2)
745	738	733
746	738	729

all verifier counts for 100s

verifier before taken at 40% model 2ft above floor	time: about 1100 hrs
verifier after (1) taken at 5%, 8in.model 2 ft above floor	time: about 1700 hrs
verifier after (2) taken btwn 20%, 6in and 20%, 8in at 2 ft	time: about 1730 hrs

All the above are count rates (c/s) as taken from MCA at end of spectrum and recorded in data book. The count rates are per "live" second, as verfied by hand calc. and comparison to a few spectra that were properly written to disk files.

Files msc41000 thru 41004 are in 20%,6in. Model from 5 to 1 ft, 1 ft intervals
Files msc41005 thru 41007 are in 20%,6in. Model at 3 ft
Files msc41cab and bab are verifier "after (2)" taken btwn 20%, 6in and 20%, 8in at 2 ft
All previous files before these were improperly written by software and lost since this problem was not discovered until we tried to copy data to floppys at end of day.

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MathCad Analysis File RLSM3.1 for 5-13-99

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Processed data from models, refer to Stats.XLS...

Count rate 8"	Volume fraction water	Count rate 8"	Volume fraction water	
$cr8 := \begin{bmatrix} 251.5 \\ 206.125 \\ 146.5 \end{bmatrix}$	$V8 := \begin{bmatrix} 19.7 \\ 11.9 \\ 5 \end{bmatrix}$	$cr6 := \begin{bmatrix} 347.8 \\ 275.3 \\ 186.4 \end{bmatrix}$	$V6 := \begin{bmatrix} 19.8 \\ 11.8 \\ 5 \end{bmatrix}$	$i := 0..2$

$xln8_i := \ln(cr8_i)$ This has x, independent variable, as count rate, since computed function is the volume fraction of water.

$xln6_i := \ln(cr6_i)$ $yln8_i := \ln(V8_i)$ $yln6_i := \ln(V6_i)$

$m8 := \mathrm{slope}(xln8, yln8)$ Power law slope, it is the power of the final function

$m6 := \mathrm{slope}(xln6, yln6)$

$c8 := \mathrm{intercept}(xln8, yln8)$ Fitting intercept, not the final function's value

$c6 := \mathrm{intercept}(xln6, yln6)$

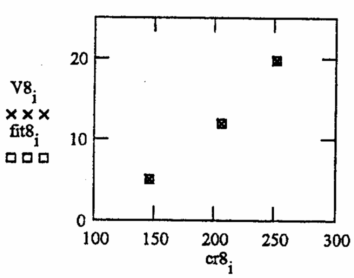
$a8 := e^{c8}$ $a6 := e^{c6}$ Final linear multiplicative coefficients

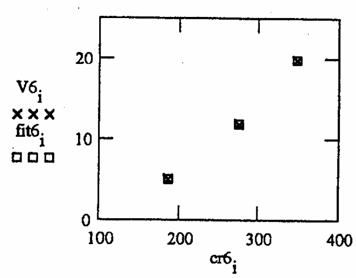
$fit8_i := a8 \cdot (cr8_i)^{m8}$ $fit6_i := a6 \cdot (cr6_i)^{m6}$

Final coefficients for Moisture Calibration

$a8 = 1.597 \cdot 10^{-5}$ $m8 = 2.537$

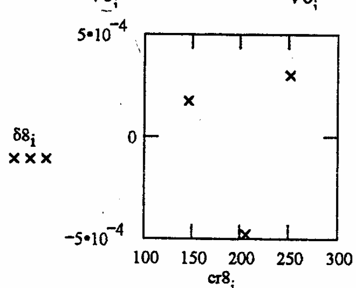
$a6 = 4.9 \cdot 10^{-5}$ $m6 = 2.206$

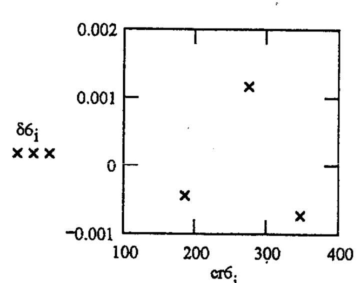




$$\delta 8_i := \frac{fit8_i - V8_i}{V8_i} \qquad \delta 6_i := \frac{fit6_i - V6_i}{V6_i}$$

Percentages for the residuals of fit from observed data.





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..................Leave in for template, but not useful for these data since no sets of 10 data collected..................

$T8_i := cr8_i \cdot 30$ $\qquad \chi 8_i := \sqrt{T8_i}$ $\qquad \sigma 8_i := \dfrac{\chi 8_i}{T8_i} \cdot \dfrac{1}{\sqrt{5}}$

In this case, the average number of samples is 5, but varies from model to model.

$T8_i =$	$\chi 8_i =$	$\sigma 8_i =$
$7.545\cdot10^{3}$	86.862	$.149\cdot10^{-3}$
$6.184\cdot10^{3}$	78.637	$.687\cdot10^{-3}$
$4.395\cdot10^{3}$	66.295	$.746\cdot10^{-3}$

These to left are per sample, and σ is for mean.

Clearly, the data and fit are inside of the statistical error for the models.

...............................end of section to ignore...

Compute comparison to RLSM3.1 of 1-14-1997 data...

$$c8 := \begin{bmatrix} 254.3 \\ 207.9 \\ 148.6 \end{bmatrix} \qquad c6 := \begin{bmatrix} 351.6 \\ 277.5 \\ 188.9 \end{bmatrix}$$

$x8_i := \ln\left(c8_i\right)$ $\qquad mm8 := \mathrm{slope}(x8, yln8)$ $\qquad cc8 := \mathrm{intercept}(x8, yln8)$

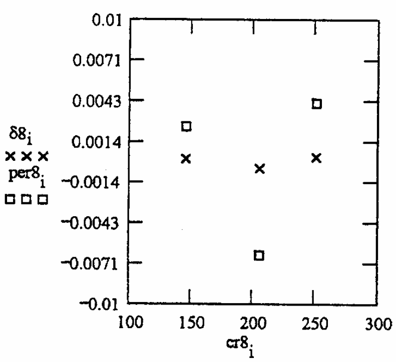
$aa8 := e^{cc8}$ $\qquad f8_i := aa8\cdot\left(c8_i\right)^{mm8}$ $\qquad per8_i := \dfrac{f8_i - V8_i}{V8_i}$

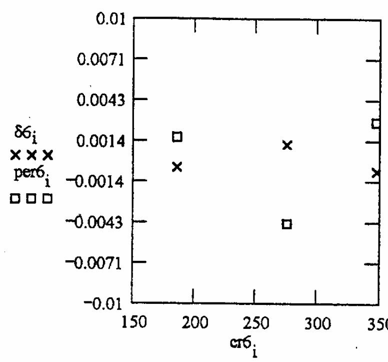
Symbols: x is present
box is 1997

$x6_i := \ln\left(c6_i\right)$ $\qquad mm6 := \mathrm{slope}(x6, yln6)$ $\qquad cc6 := \mathrm{intercept}(x6, yln6)$

Comparison of residuals...

$aa6 := e^{cc6}$ $\qquad f6_i := aa6\cdot\left(c6_i\right)^{mm6}$ $\qquad per6_i := \dfrac{f6_i - V6_i}{V6_i}$





The possible sources of error for the basic calibration contain at least the following:

- counting statistics
- tool position vertically
- tool position-centered in casing
- tool tilt from true vertical
- tool average wobble or oscillations during data collection
- instrument electronic noise
- instrument drift
- electronic dead time
- mca pileup
- mechanical stability of source and detector positioning
- model assignment (bulk versus depth of investigation)
- temperature variations

$aa8 = 1.412\cdot10^{-5}$

$mm8 = 2.555$

$aa6 = 4.504\cdot10^{-5}$

$mm6 = 2.217$

Even though 6" coefficients appear to have changed, the function has not.

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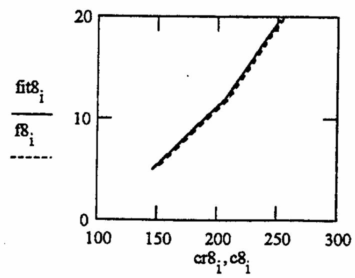
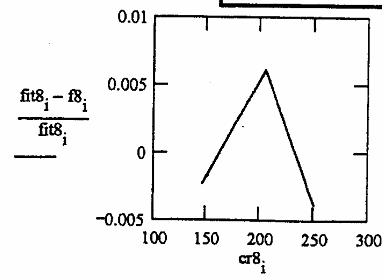
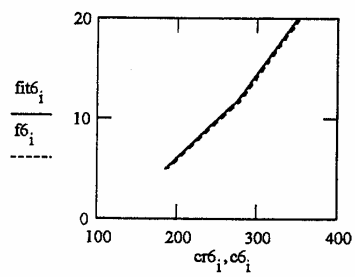
Fit results for moisture now and 1997



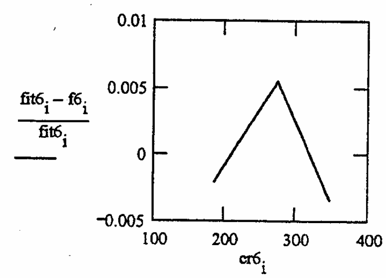
Percent difference for 8in results now and 1997



Fit results for moisture now and 1997



Percent difference for 6in results now and 1997



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